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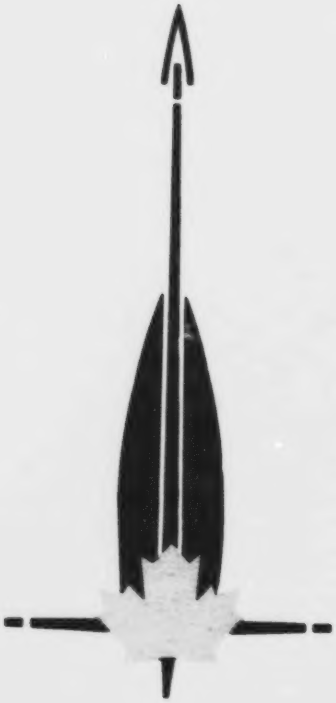

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Prepared by:

S. Lantos

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16. Abstract

This project was undertaken to develop computer software incorporating a method or methods suitable for predicting the manoeuvring characteristics of a vessel during the preliminary design phase. In addition, a "Sea Trials Program" was proposed which specified a standard set of manoeuvring sea trials, their execution procedures, the data to be recorded and the methods for recording the data.

An extensive literature survey resulted in the selection of a time domain simulation algorithm and two sets of empirical formulae to predict vessel manoeuvring characteristics during turning circle, zigzag, spiral and crash stop manoeuvres.

A reasonable level of correlation between results of full-scale trials using a laker and a ferry and the numerical results was achieved, but sensitivity analysis confirmed that the computer model could give misleading results at the design stage where some key input parameters may not be known with sufficient accuracy. The model is not yet general enough to cope with all configurations and adverse environmental conditions.

It was concluded that current efforts to introduce international manoeuvring standards may be premature.

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16. Résumé

La recherche visait la mise au point d'une ou de plusieurs méthodes assistées par ordinateur pour la prévision des caractéristiques de giration d'un navire encore à l'étude. De plus, elle a débouché sur des propositions concernant les manoeuvres à effectuer en mer afin de mesurer les qualités manoeuvrières du navire, le mode opératoire, les données à rassembler et les techniques d'enregistrement de celles-ci.

La recherche documentaire poussée a permis de sélectionner un algorithme de simulation dans le domaine temporel ainsi que deux séries d'équations empiriques sur les caractéristiques manoeuvrières dans les girations, les zigzags, les spirales et les renversements de vapeur.

La recherche a montré une bonne corrélation entre les résultats théoriques et ceux des essais en mer effectués à bord d'un cargo hors mer et d'un traversier. Toutefois, les analyses de sensibilité ont révélé que la méthode informatique risque de donner des résultats susceptibles de fausser les calculs si certains paramètres de base ne sont pas connus avec une précision suffisante. De plus, le modèle en question n'est pas encore paramétrable en fonction de toutes les configurations possibles ni de toutes les conditions extérieures défavorables.

Le rapport arrive à la conclusion qu'il est peut-être encore trop tôt pour commencer la promotion d'une norme internationale concernant la manoeuvrabilité des navires.

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SUMMARY

1. INTRODUCTION

German & Milne Inc. was awarded a contract by the Transportation Development Centre of Transport Canada to investigate the determination of ship manoeuvrability. The project was initiated in response to the recommendations of the International Maritime Organization (IMO), which is currently involved in an ongoing process related to the development of international manoeuvring standards.

The primary objectives of this project were to:

- identify and justify a method or methods suitable for predicting the manoeuvring characteristics of a vessel during the preliminary design phase;
- develop computer software, incorporating the preferred methods(s) previously identified; and
- compare the results of the computer analysis to data contained in a manoeuvring database and also to the results of full-scale ship trials.
- develop a "Sea Trials Program" outlining several manoeuvres to be conducted after a vessel is constructed, the method for executing the manoeuvres, data to be recorded and the data recording equipment required for the trials.

2. APPROACH/METHODOLOGY

An extensive literature survey was conducted during the early stages of the project to identify possible methods available to predict the manoeuvring response of a vessel. A time domain simulation method was selected as the primary component for the computer program written for this study.

This simulation method was in principle capable of modelling all turning manoeuvres normally undertaken. In addition to this algorithm, empirical formulae were identified and incorporated into the software. The empirical formulae predicted the characteristics of the turning circle manoeuvre and also the head reach during the crash stop manoeuvre, which the simulation method did not cover.

To validate the mathematical model, full scale trials were conducted on the M.V. "Algowest" and the M.V. "Atlantic Freighter". The trials included the zigzag manoeuvre, turning circle manoeuvre, crash stop and spiral manoeuvre.

These trials were conducted in accordance with the requirements of the "Sea Trials Program", which was developed as a part of this project. The "Sea Trials Program" was based upon existing methods for conducting full scale trials and at the same time, the program met existing IMO requirements for obtaining information necessary for a ship's pilot card, Wheelhouse/Bridge Poster, and Manoeuvring Booklet.

3. SUMMARY OF RESULTS

Computer simulations were conducted using data sets representing the M.V. "Algowest" in a loaded condition and ballast condition, and the M.V. "Atlantic Freighter" in a ballast departure condition. The simulations included:

- 35^{o} turning circles to port and starboard;
- $10^{o}/10^{o}$ and $20^{o}/20^{o}$ zigzag manoeuvres; and
- spiral manoeuvres starting with rudder angles of 15^{o} to port and starboard.

The parameters which were specifically recorded were the advance, transfer, tactical diameter, steady turning diameter, steady turning speed, overshoot angle, overshoot width of path, reach, period and the constant yaw rate for a specific rudder angle.

Empirical estimates of the turning circle characteristics and head reach during the crash stop were also calculated. In addition to the above, information contained in the Canadian Coast Guard's manoeuvring database was accessed to compare the values for head reach, advance, transfer and tactical diameter which it contains.

All of the above predictions were compared to the results obtained from the full scale trials. The trials data were assumed to be accurate, as the tests were conducted in ideal environmental conditions, within the range of a microwave positioning system, and with the ships operating in known conditions of loading and powering.

3.1 M.V. "Algowest" Manoeuvring Results

The computer simulation predictions of the turning circle manoeuvre for the M.V. "Algowest" in both load conditions were within 10% of the tactical diameter and steady turning diameter, and 16% of the advance and transfer. The steady turning speed was overestimated by the computer model.

Empirical estimates were more variable than the simulated results for the turning circle manoeuvre. For starboard turns, the estimates for all parameters except the final speed were within 13% of the full scale data; however, the same characteristics for the port turns were not predicted accurately. The speed predictions were also inconsistent.

Predictions for the zigzag manoeuvre were not as satisfactory, apart from the predicted overshoot angle during the $10^0/10^0$ manoeuvre in the loaded condition. All remaining parameters were either overestimated or underestimated by at least 15%.

The computer model was unable to accurately predict the constant yaw rate for a particular rudder angle during the spiral manoeuvre. In all cases the model overestimated the yaw rate by a minimum of 50%. Notwithstanding the poor predictions of yaw rate, the model did predict the correct trends which the ship exhibited during the full scale trials. For example, the M.V. "Algowest" was dynamically stable in the ballast condition which was predicted by the model. Similarly, the model predicted that the M.V. "Algowest" would be dynamically unstable in the loaded condition, and this was exhibited during the full scale trials.

The empirical estimate of head reach was within 15% for the ballast condition; however, it was too conservative when the vessel was in the loaded condition.

3.2 M.V. "Atlantic Freighter" Manoeuvring Results

The computer simulation consistently underestimated the parameters of the turning circle manoeuvre by 15% to 29%. Empirical estimates of the tactical and steady turning diameters were within 10% of the full scale data; however, the remaining parameters were not predicted with the same degree of accuracy.

The parameters of the zigzag manoeuvres were not estimated correctly by the model, except for the reach in the $10^{o}/10^{o}$ manoeuvre and the overshoot width of path in the $20^{o}/20^{o}$ manoeuvre. Both of these parameters were predicted within 10% of the full scale value.

Simulation of the spiral manoeuvre for the M.V. "Atlantic Freighter" was not accurate in comparison to the full scale data. However, the model did indicate the correct trend of dynamic instability exhibited by the vessel during the trials.

The empirical estimate of head reach during the crash stop manoeuvre was accurate.

3.3 Sensitivity Analysis

From a review of the computer simulation results in comparison to the full scale data, it was evident that the model required further refinements and/or modifications. It was also realized that certain parameters used in the model were influencing the results much more than other variables. A limited sensitivity analysis was conducted to identify the key model parameters.

The analysis revealed that the simulation results were highly sensitive to the pitch-diameter ratio and the rudder wake fraction. Varying these two parameters within ranges that would be used by a naval architect during the early stages of a design affected the simulation results by more than 30% in some cases.

4. CONCLUSIONS

It is concluded, as a result of this project, that standardization of manoeuvring trials procedures is a necessary component of any international manoeuvrability initiative. The costs and other impacts of using such procedures are low, and data must be collected in a consistent fashion to make it meaningful. This is highlighted in the scatter shown by existing data for nominally similar ships.

A methodology has been selected, developed and implemented in a computer program for predicting ship manoeuvrability . Tested against accurate full-scale trials results, this method has proven to give reasonably accurate results for a number of manoeuvres. However, the method has a number of significant limitations, which mean that it could not be used reliably as the sole design tool for a vessel required to meet specific performance standards. In its current state of development, it can be used to check the quality of full-scale, deep-water data for a wide (though not comprehensive) range of ships.

The unsatisfactory nature of methods currently available for performance prediction, combined with little published rationale on how suitable performance criteria should be formulated, leads the authors to conclude that the introduction of international or national standards for manoeuvrability would be premature. Adequate manoeuvrability is however clearly important to the minimization of accidents. Canada should therefore continue its current efforts to develop more complete understanding of both the theoretical basis of manoeuvring performance and its practical consequences.

SOMMAIRE

1.0 INTRODUCTION

German & Milne Inc. a reçu du Centre de développement des transports de Transports Canada un contrat de recherche sur une méthode permettant de mesurer les qualités manoeuvrières d'un navire. Ce marché visait à donner suite aux recommandations de l'Organisation maritime internationale (OMI), laquelle participe à un programme permanent ayant pour but l'élaboration de normes internationales sur la manoeuvrabilité des navires.

Les objectifs de la recherche étaient les suivants:

- trouver et justifier une ou des méthodes pour la prévision des caractéristiques de giration d'un navire encore à l'étude;
- élaborer un logiciel fondé sur la ou les méthodes sélectionnées;
- comparer les résultats obtenus par cette méthode analytique à la base de données existante ainsi qu'aux résultats des essais effectués en mer;
- étudier un programme d'essais en mer comportant un certain nombre de manoeuvres précises à être effectuées par le navire une fois construit et prévoyant le mode opératoire, les données à rassembler ainsi que les techniques d'enregistrement de celles-ci.

2.0 MÉTHODE DE RECHERCHE

Une recherche documentaire poussée a été lancée au début des travaux afin de recenser les diverses méthodes de prévision des qualités manoeuvrières d'un navire. Elle a permis de sélectionner un algorithme de simulation dans le domaine temporel devant servir de base au programme informatique nécessaire.

Cet algorithme devait, en principe, rendre possible la simulation de toutes les manoeuvres de giration normales. En outre, des séries d'équations empiriques ont été obtenues et intégrées au logiciel; elles permettent de déterminer par calcul les caractéristiques manoeuvrières d'un navire ainsi que la distance rectiligne d'immobilisation en cas de renversement de la vapeur, données que l'algorithme ne permet pas d'obtenir.

Dans le but de valider ce modèle mathématique, des essais en mer ont été effectués à bord des N.M. Algowest et Atlantic Freighter, qui ont été soumis à des manoeuvres comportant des girations, des zigzags, des spirales et des renversements de la vapeur.

Ces essais ont été conformes au programme étudié dans le cadre de la présente recherche ainsi qu'aux prescriptions de l'OMI, lesquelles visaient l'information que doivent contenir la carte de pilotage, le carnet de manoeuvres et la pancarte des manoeuvres devant être affichée dans la passerelle de navigation.

3.0 SOMMARIE DES RÉSULTATS

Des simulations par voie informatique ont été faites à l'aide des données figurant le N.M. Algowest en charge et sous lest, et le N.M. Atlantic Freighter chargé de lest et de combustible. Les manoeuvres simulées ont été les suivantes:

- girations à 35° de braquage à bâbord et à tribord;
- zigzags 10°/10° et 20°/20°; et
- spirales lancées avec un angle de braquage de 15°, à bâbord et à tribord.

Les paramètres pris en compte ont été l'avance, le transfert, le diamètre tactique, le diamètre de giration en régime stabilisé, la vitesse de giration en régime stabilisé, l'angle de dérive, la distance de dérive, le temps de réponse, la période et le taux angulaire de giration en fonction de l'angle de braquage.

Grâce aux équations empiriques, des valeurs estimatives ont pu être obtenues sur les caractéristiques de giration et la distance rectiligne d'immoblisation. En outre, on a consulté la base de données de la Garde côtière canadienne sur les qualités manoeuvrières de ses navires afin de comparer les valeurs qu'elle renferme aux valeurs théoriques en ce qui concerne la distance rectiligne d'immobilisation, de l'avance, du transfert et du diamètre tactique.

Toutes les valeurs prévisionnelles ont été par la suite comparées aux résultats des essais en mer, tenus pour fiables étant donné que ces derniers se sont déroulés dans des conditions extérieures idéales, à portée du système de localisation hyperfréquence ainsi que dans des conditions de charge et à des régimes de puissance connus.

3.1 RÉSULTATS CONCERNANT LE N.M. ALGOWEST

La simulation des manoeuvres de giration de ce navire dans les deux conditions de charge a débouché sur des valeurs théoriques à 10 p. 100 près des valeurs réelles du diamètre tactique et du diamètre de giration en régime stabilisé, et à 16 p. 100 près de l'avance et du transfert. Quant à la vitesse de giration en régime stabilisé, les valeurs théoriques ont toutes été trop élevées par rapport aux valeurs réelles.

Les valeurs obtenues des équations empiriques ont fluctué beaucoup plus que les valeurs correspondantes tirées de la simulation des manoeuvres de giration. Dans les girations à tribord, les valeurs estimatives ont été à 13 p. 100 près des valeurs réelles pour tous les paramètres, à l'exception du diamètre de giration en régime stabilisé, tandis que dans les girations à bâbord, les valeurs obtenues ont été d'une précision médiocre. Quant aux vitesses, là aussi les prévisions manquaient de précision.

Les valeurs prévisionelles concernant les zigzags n'ont pas été aussi précises, à l'exception de la valeur théorique de l'angle de dérive durant les zigzags 10°/10°, en charge. Pour tous les autres paramètres, les valeurs estimatives ont été au-dessus ou au-dessous des valeurs réelles par 15 p. 100, au moins.

Le modèle mathématique n'a pas permis de figurer avec précision le taux anglaire de giration en fonction de l'angle de braquage durant les manoeuvres en spirale. Dans tous les cas, les valeurs théoriques de taux angulaire de giration ont dépassé les valeurs réelles d'au moins 50 p. 100. Malgré ces faiblesses, le modèle a cependant pu déterminer avec précision certaines particularités du N.M. Algowest, mises en évidence durant les essais en mer; par exemple, qu'il était dynamiquement stable sous lest, mais dynamiquement instable en charge.

3.2 RÉSULTATS CONCERNANT LE N.M. ATLANTIC FREIGHTER

La simulation des manoeuvres de giration de ce navire a systématiquement débouché sur des valeurs théoriques de 15 à 29 p. 100 au-dessous des valeurs réelles. Quant aux valeurs obtenues des équations empiriques concernant le diamètre tactique et le diamètre de giration en régime stabilisé, elles ont été à 10 p.

100 près des valeurs réelles. Pour les autres paramètres, les valeurs correspondantes n'ont pas été aussi précises que les précédentes.

Dans les zigzags, le modèle mathématique n'a pas permis de calculer avec précision la valeur estimative de chacun des paramètres, à l'exception du temps de réponse dans les zigzags 10°/10° et de la distance de dérive dans ceux à 20°/20°, pour lesquels les valeurs estimatives ont été à 10 p. 100 près des valeurs réelles.

La simulation des manoeuvres en spirale a débouché sur des valeurs estimatives imprécises, comparativement aux valeurs réelles. Cependant, le modèle mathématique a pu déterminer l'instabilité dynamique dont souffre ce navire, et qui a été mise en évidence lors des essais en mer.

La valeur obtenue des équations empiriques concernant la distance rectiligne d'immobilisation après un renversement de la vapeur a été assez proche de al valeur réelle.

3.3 ANALYSE DE LA SENSIBILITÉ

Une analyse des valeurs théoriques comparées aux valeurs réelles montre que le modèle mathématique doit être affiné et éventuellement modifié. Il a également été constaté que certains paramètres du modèle influençaient les résultats beaucoup plus que d'autres. Une analyse partielle de sensibilité a été faite afin d'isoler les paramètres auxquels le modèle était le plus sensible.

L'analyse a montré que le modèle était très sensible au rapport pas-diamètre et à l'effet de sillage. En faisant varier ces deux paramètres dans les plages qu'un bureau d'architectes navals envisagerait tôt dans le processus de conception, les résultats ont parfois varié par une marge supérieure à 30 p. 100.

4.0 CONCLUSIONS

La recherche a montré que l'initiative lancée par l'OMI passe nécessairement par une normalisation des essais pour mesurer les qualités manoeuvrières d'un navire. Les conséquences financières et autres de cette normalisation sont faibles; mais, pour être utiles, les données doivent être rassemblées rationellement, faute de quoi c'est l'incohérence, comme en témoigne la dispersion dans les données qui se rapportent pourtant à des navires identiques dans leurs caractéristiques.

La méthode choisie, développée et mise en oeuvre a débouché sur un programme informatique pour la prévision des qualités manoeuvrières de navires. Confrontée aux résultats des essais en mer, cette méthode a permis d'obtenir des résulats assez précis sur un certain nombre de manoeuvres. Mais, à cause de ses limites d'utilisation, elle ne peut fiablement être considérée comme un outil de calcul capable de remplacer tous les autres pour l'étude d'un navire devant être doté de qualités manoeuvrières conformes aux critères établis. A l'état actuel de son développement, cette méthode permet de procéder à une vérification qualitative des données tirées d'essais en haute mer pour une gamme de navires certes vaste, mais non exhaustive.

Les incertitudes entourant les méthodes de prévision connues et celles concernant la formulation et l'adéquation des critères applicable font croire aux auteurs du présent rapport qu'il serait prématuré d'engager la promotion d'une normalisation à l'échelle nationale ou internationale. Toutefois, l'objectif d'une mesure adéquate de la manoeuvrabilité reste valide, ne serait-ce que pur réduire les collisions. C'est pourquoi le Canada devrait poursuivre ses efforts vers la connaissance plus approfondie des principes en jeu et des réalisations concrètes susceptible d'en découler.

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1.0 INTRODUCTION

In recent years, increasing attention has been paid to the manoeuvring characteristics of large merchant ships. These characteristics intuitively appear to influence the probability that a ship will be involved in accidents such as collisions, ramming and groundings, or that it will require assistance in navigating in restricted waters. Various national and international initiatives have therefore been prepared, and in some cases implemented, to define the performance of existing ships and to regulate the characteristics and/or operations of new vessels.

A recent study (ref. 23) established a manoeuvring database containing results from full-scale trials conducted on Canadian merchant vessels. These findings were presented to the International Maritime Organizations (IMO), as partial fulfilment of the interim guidelines established by IMO (ref. 4).

IMO also requested that member nations develop techniques for predicting the manoeuvring qualities of vessels during the preliminary design phase of a ship design and construction project. It was further requested that the developed models be tested using full-scale trials data. The Transportation Development Centre (TDC) sponsored work to meet the IMO requests, and to fulfil a number of specific Canadian requirements.

The primary objectives of this project were to:

- identify and justify a method or methods suitable for predicting the manoeuvring characteristics of a vessel during the preliminary design phase;

- develop a standard set of sea trials which would guarantee the collection of accurate trials data;

- develop computer software, incorporating the preferred method(s) previously identified; and

- compare the results of the computer analysis to data contained in a manoeuvring database (ref. 23), and also to the results of full-scale ship trials.

The results of this study will be forwarded to the Canadian Coast Guard (CCG), who in turn, will make presentations to the IMO summarizing the conclusions. It is anticipated that the results of this project will provide CCG with sufficient information to adequately represent Canada during future discussions regarding the development of international manoeuvring standards.

2.0 LITERATURE SURVEY

An extensive literature review was conducted during the first two weeks of the project. The purpose of the review was to identify a method (or methods) which a naval architect could use in the preliminary design phase to obtain an initial estimate of a vessel's manoeuvring characteristics.

There are four basic manoeuvres which are conducted to assess a vessel's manoeuvrability. These are the turning circle, zigzag, spiral, and crash stop manoeuvres. The literature review, (see bibliography, Appendix A), revealed that a majority of work was concentrated on developing means of predicting the various parameters associated with the turning circle manoeuvre, and that a relatively small amount of research was directed towards the other manoeuvres.

To fulfill the project objective of being able to predict and analyze each of the aforementioned primary manoeuvres, German & Milne opted for a time simulation algorithm (ref. 1). The algorithm solves the differential equations of motion, providing the ship's track as a function of time for each of the manoeuvres except the crash stop.

The literature review did not identify any methodologies which could simulate the crash stop manoeuvre as a function of time. Therefore, an empirical estimate was chosen (ref. 2) which predicted the head reach of a vessel during the crash stop. As an additional check, an empirical method was chosen to estimate the turning circle characteristics (ref. 3).

Details of each of the algorithms used are contained in Section 5.0 of this report.

3.0 SEA TRIALS PROGRAM

3.1 DETAILS OF THE PROPOSED MANOEUVRES

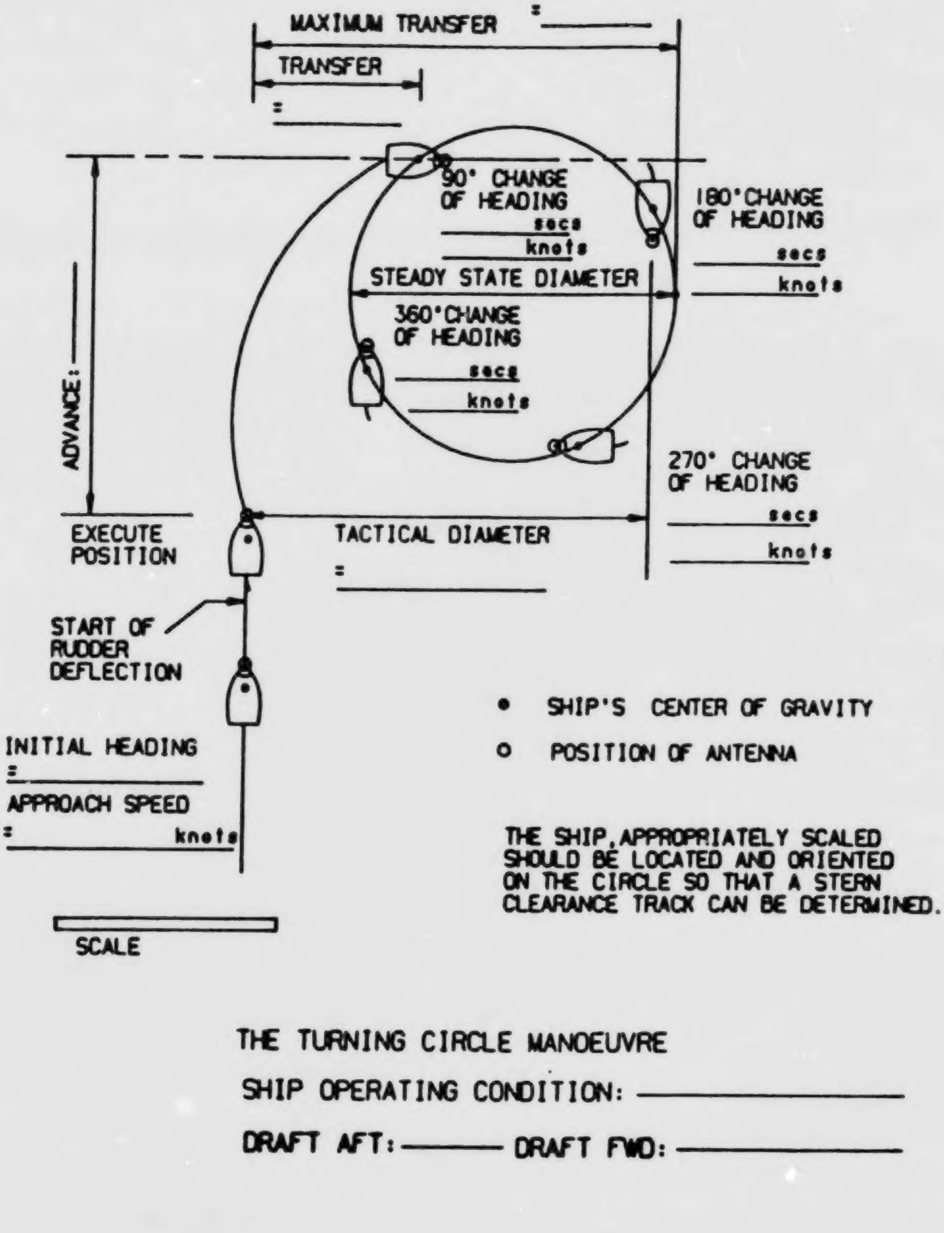
In keeping with the guidelines (ref. 4) issued by the International Maritime Organization (IMO), and information contained in Resolution A209 (VII) (ref. 24), several individual sea trials have been proposed. The results of these standardized manoeuvres will provide a measure of the inherent controls fixed stability of a vessel. The proposed manoeuvres (all of which are recommended by IMO) are as follows:

- The turning circle manoeuvre
- The zigzag (or Kempf) manoeuvre
- The Dieudonne spiral manoeuvre
- The crash-stop manoeuvre
- The pull-out manoeuvre
- The lateral thrusters manoeuvre; and
- Man-Overboard - Williamson turn manoeuvre.

A brief description of each of the standard manoeuvres, along with a discussion of the significance of the results, is given in the following sections.

3.1.1 Turning Circle Manoeuvre

The turning circle manoeuvre is an indicator of rudder effectiveness to produce steady-state turning characteristics. Normally it is conducted for different approach speeds, using the maximum allowable rudder angle at that speed. The four numerical measures which generally characterize the turning path of a vessel are the advance, transfer, tactical diameter, and steady state turning diameter, as shown in Figure 3-1.



THE TURNING CIRCLE MANOEUVRE

SHIP OPERATING CONDITION: ____________

DRAFT AFT: ______ DRAFT FWD: ____________

Figure 3-1: Characteristics of a Turning Circle Manoeuvre

i) Advance is the distance from the origin at "execute" to the X-axis of the ship after a 90° change of heading.

ii) Transfer is the distance from the original approach course to the origin of the ship when it has changed heading by 90°.

iii) Tactical diameter is the distance from the approach course to the X-axis of the ship after a 180° change of heading.

iv) Steady-state turning diameter is a measure of the turning circle diameter once the speed, drift angle and turning diameter reach steady values. It is usually less than the tactical diameter.

One other important feature of this test is the loss of speed during the manoeuvre. The rudder maintains the hull at an angle of attack (i.e. the drift angle), in order to develop the "lift" necessary to cause the ship to accelerate towards the centre of the turn. In so doing, the drag increases resulting in a loss of speed. The speed during the turn, usually steadies once the vessel has changed heading by approximately 90°.

3.1.2 ZigZag (or Kempf) Manoeuvre

The zigzag manoeuvre provides a quantitative measure of the effectiveness of the rudder to check changes of the ship's heading angle. The procedure for executing the manoeuvre involves several changes of rudder angle as described in Appendix "E". Figure 3-2 shows the results of a zigzag manoeuvre which went through five executes.

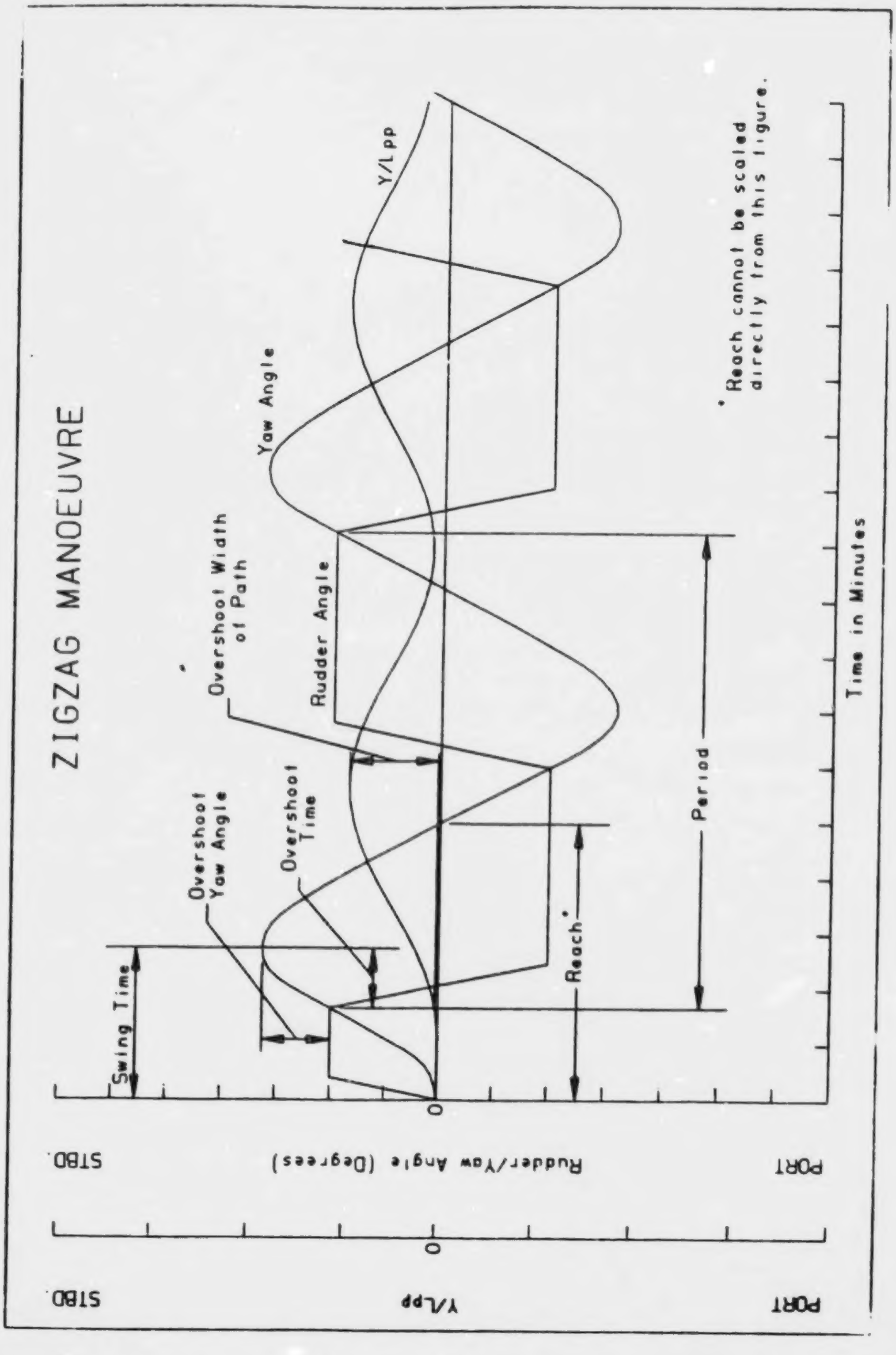


Figure 3-2: Characteristics of a Zigzag Manoeuvre

The principal numerical measures of control obtained from the zigzag manoeuvre are defined as follows (refers to Figure 3-2):

- The reach is the distance travelled in the global x-direction from the start of the manoeuvre to the time when the yaw angle of the vessel first returns to the original heading;

- The period is the elapsed time between the first and third changes of rudder angle;

- The overshoot yaw angle is the difference between the maximum yaw angle and the ordered rudder angle and is usually measured after the first change of rudder angle; and

- The overshoot width of path is the difference between the maximum distance travelled normal to the ship's original path and the distance travelled at the time of the change of rudder angle.

The overshoot yaw angle and width of path parameters are numerical measures which indicate the amount of anticipation required of a helmsman while operating in restricted waters. The magnitude of the yaw angle overshoot decreases with increased stability but increases with increased rudder effectiveness.

On first examination this statement appears to be in error, however, the explanation is quite simple. If a vessel has good turning ability, then it will tend to continue turning in the direction of the first rudder execution after the second execution has been given. Because of the good turning performance, the vessel's momentum is more rapidly changed in the direction of the first execution, therefore making it more difficult to change direction at the second execute, hence increasing the overshoot angle. If, on the other hand, the vessel exhibits good controls-fixed stability, then the momentum of the vessel is more gradually altered in the direction of the first rudder execute and the vessel can react more quickly on the second execute.

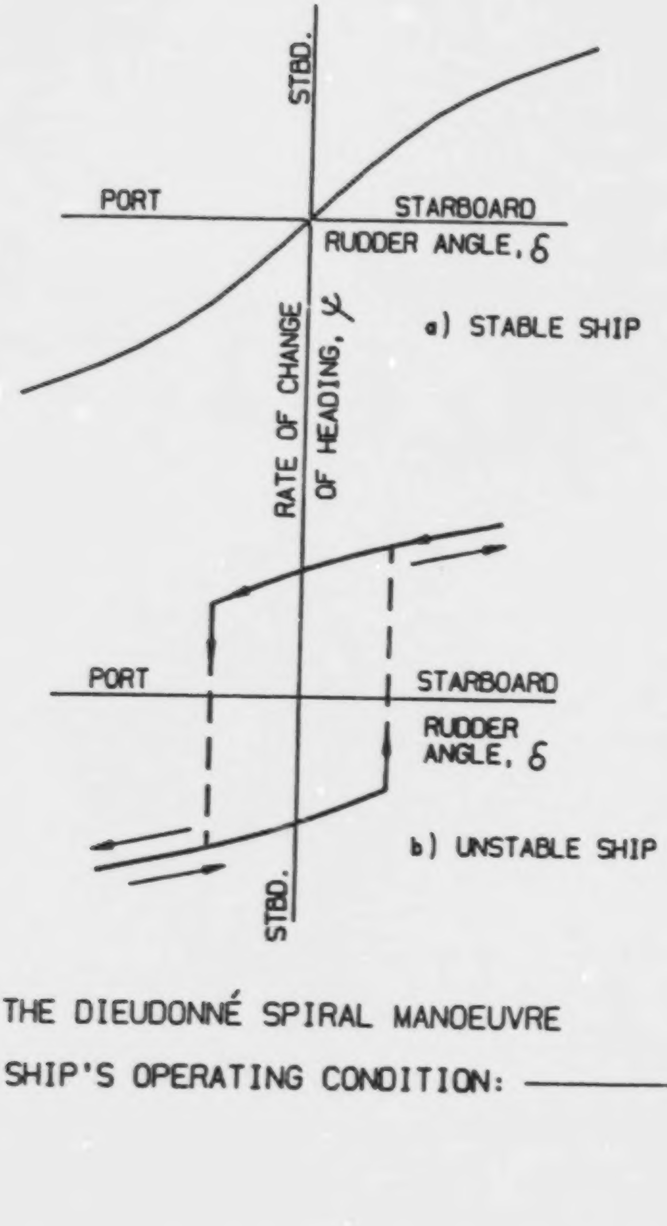
The overshoot width corresponds to the difference between the maximum distance travelled normal to the ship's original path and the distance normal to the ship's original path at the time of the second execute. The overshoot width of path decreases with both increased stability and increased rudder effectiveness.

It can also be said that the results of the zigzag manoeuvre are quite speed dependent. In general, for any given ship, the overshoot yaw angle and the overshoot width of path increase with increasing speed.

3.1.3 Dieudonné Spiral Manoeuvre

The Dieudonné spiral manoeuvre provides a quantitative measure of the directional stability characteristics of a ship. Because of the difficulty in recording the low angular velocities at small rudder angles, the manoeuvre should be executed in still air and calm-water conditions. The procedure for conducting the spiral manoeuvre is described in Appendix "E".

At the conclusion of this test, a plot of the steady yawing rate versus rudder angle, can be obtained. An example is shown in Figure 3-3 for two ships. A resultant plot, such as Figure 3-3 (a) for the stable ship, is typical of a ship possessing controls fixed, straight line stability. If however, the plot forms a "hysteresis" loop, as shown in Figure 3-3(b), the ship is considered directionally unstable. The existence of a hysteresis loop indicates that the ship may continue to turn against the applied rudder angle.



THE DIEUDONNÉ SPIRAL MANOEUVRE

SHIP'S OPERATING CONDITION: ________

Figure 3-3: Characteristics of a Spiral Manoeuvre

3.1.4 Crash Stop Manoeuvre

The crash stop manoeuvre provides a means of assessing a vessel's stopping ability, primarily from the point of view of avoiding collision.

The most common procedure for the crash stop manoeuvre is to decelerate the ship by reversing the ship's throttles from full speed ahead to full speed astern at a maximum allowable rate, while holding the rudder at amidships. In compliance with the recommended information, the proposed crash stop manoeuvre includes various tests of different speed combinations so that curves of the vessel's stopping ability can be generated if so desired.

The parameters which are most important to quantify are as follows:

i) Head Reach which is defined as the distance travelled in the direction of the ship's initial course.

ii) Track reach which is defined as the total distance travelled along the ship's path.

iii) Lateral deviation which is defined as the distance either to port or starboard, measured normal to the ship's path.

Unfortunately, the ship is usually directionally uncontrollable once the throttle is reversed, therefore the path of the ship is, to a large extent, determined by the ambient conditions.

3.1.5 Pull-Out Manoeuvre

The pull-out manoeuvre provides a relatively quick and easy indication of a ship's course stability. In this manoeuvre, the ship is placed in a steady rate of turn by the application of the rudder at a specific angle. The rudder is then returned to midships and measurements are recorded, of the decrease in the ship's turning rate.

If a ship is stable, the rate of turn will decay to zero for turns to both port and starboard. If the ship has a steering bias, the rates of turn will decay to the same small rate of turn to either port or starboard, depending upon which side the bias exists.

If the ship is unstable, as shown in Figure 3-4, the rate of turn will decay to some residual rate of turn. This residual rate of turn should approximately equal the rate of turn corresponding to zero rudder angle, as determined by the spiral manoeuvre.

3.1.6 Thruster Tests

The thruster manoeuvre is performed to determine the effect of forward speed or turning performance. The information obtained from the thruster tests indicates the steady rate of turn which can be achieved using the thruster at zero forward speed, and also the decrease in effectiveness of the thruster as the forward speed of the ship is increased. Complete details for executing the thruster tests are contained in Appendix "E".

In compliance with reference 24, diagrams of turning performance at zero forward speed in the full load or ballast condition are to be shown, as well as diagrams showing the effect of forward speed on turning performance. Typical results are illustrated in Figure 3-5.

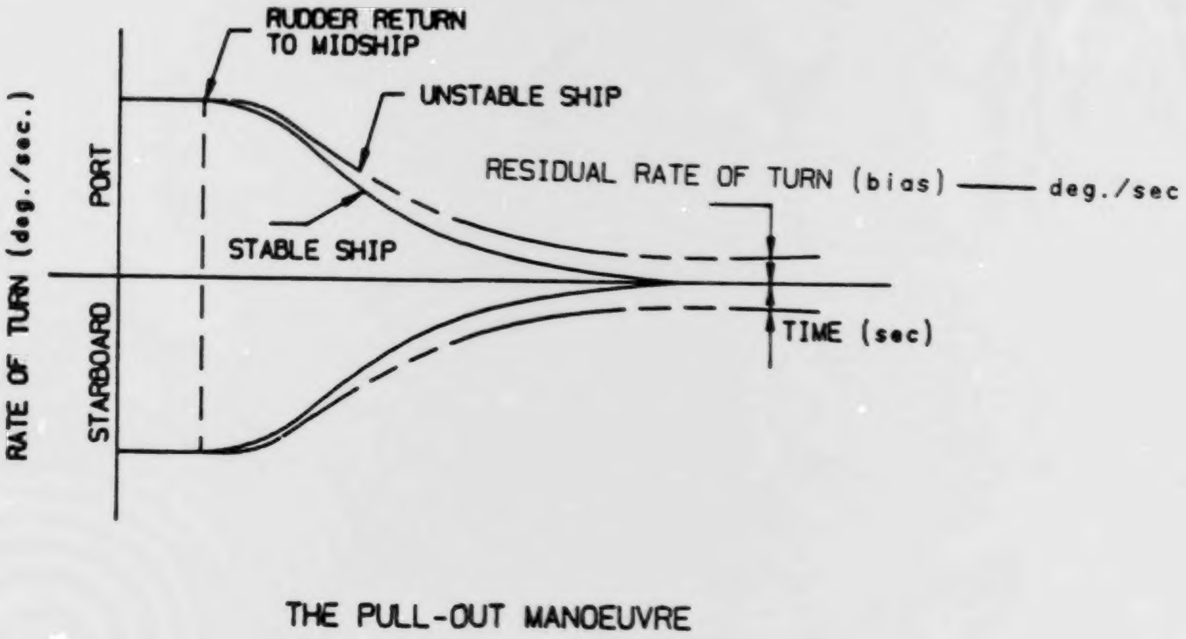
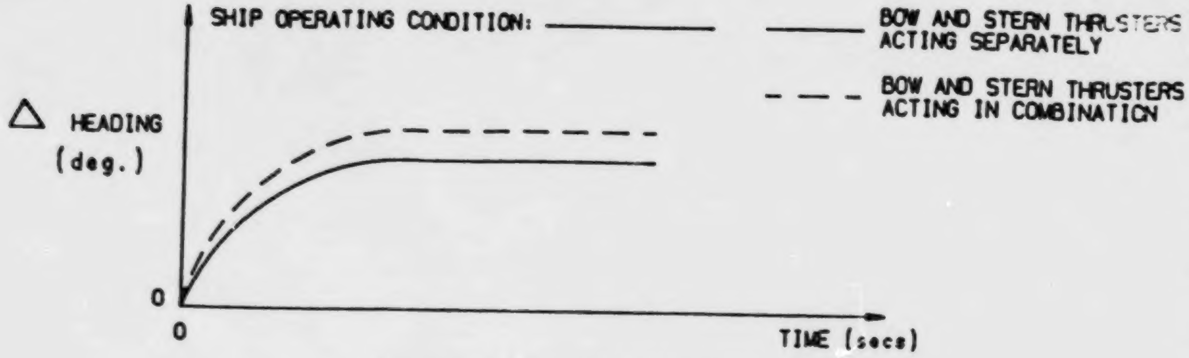
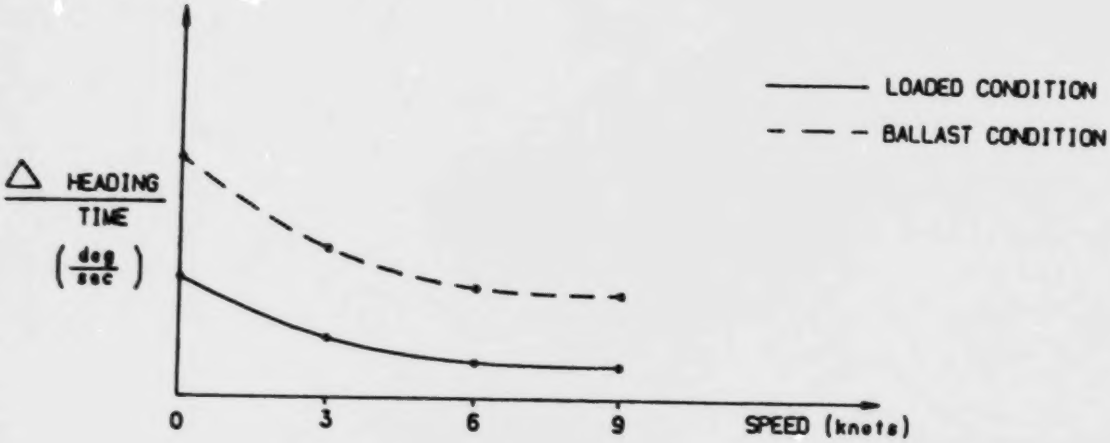


Figure 3-4: Characteristics of a Pull-Out Manoeuvre



TURNING PERFORMANCE AT ZERO FORWARD SPEED



THE EFFECT OF FORWARD SPEED ON TURNING PERFORMANCE

Figure 3-5: Characteristics of a Thruster Test

3.1.7 Williamson Turn Manoeuvre

A trial of a man-overboard manoeuvre, (Williamson Turn), is specifically requested by IMO in reference 24. The Williamson Turn is a simple manoeuvre, especially effective in reduced visibility as it makes good the vessel's reciprocal track. The Williamson Turn is also used in situations when it is believed that a man fell overboard some time previously and is now no longer in sight.

For the man-overboard simulation, a suitable marker will be used to represent the unfortunate victim. A diagram of the ship's for presentation of the results, as shown in Figure 3-6. The procedure for executing the man-overboard trial is described in Appendix "E".

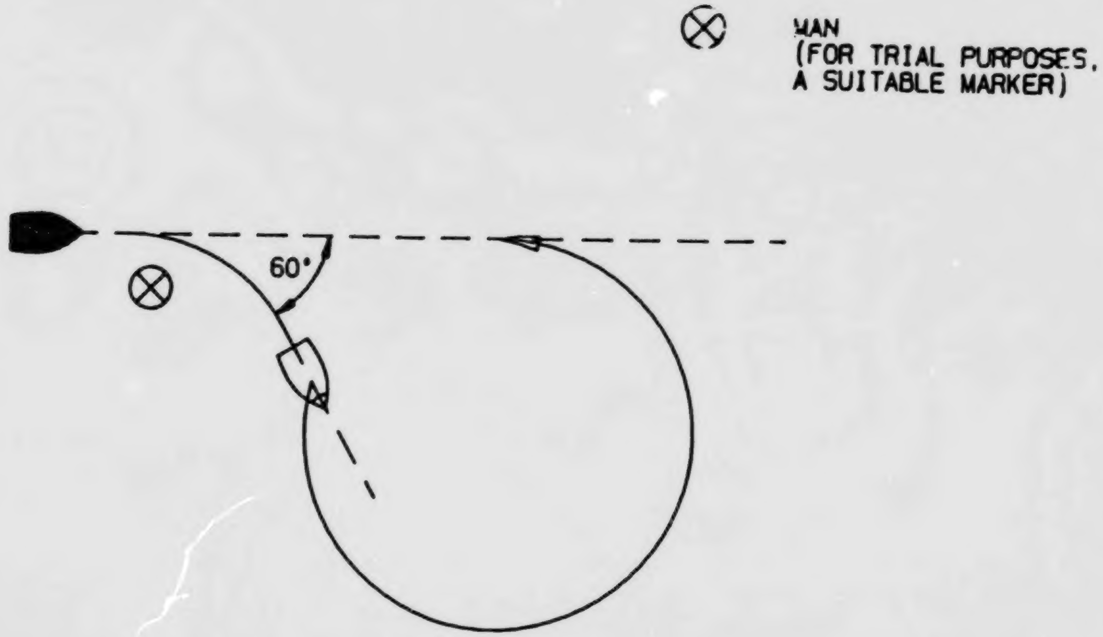
3.2 TRIAL REQUIREMENTS

A brief description of the various trial requirements for the proposed manoeuvres is given in the following sections. Constraints such as vessel approach speed and minimum water depth have been addressed as well as the instrumentation for data collection and corresponding accuracy requirements. Failure to comply with these trial requirements may result in spurious data.

3.2.1 Trial Area - General

The selection of a trial area is bound by the constraints imposed by the method of tracking, minimum water depth requirements, accessibility and traffic in the intended area.

The use of a microwave positioning system makes it possible to achieve satisfactory accuracy over a considerable area. The system limitations depend mainly on the coastline configuration of the intended trial area. Factors which contribute to the clarity



ELAPSED TIME: ____________________

WILLIAMSON TURN MANOEUVRE

Figure 3-6: Characteristics of the Williamson Turn Manoeuvre

and strength of the signal include good triangularization of slave stations as well as sufficient height above the ground and sea level of both the master and slave stations.

The ship's doppler speed log may be used for tracking during the crash stop manoeuvre, provided that the tracking reference used corresponds to bottom track mode and meets the accuracy requirements outlined in section 3.2.5. In addition to the system's limitation on maximum water depth to ensure a bottom lock, the intended trial area must foremost satisfy the SNAME minimum depth requirements for deep water conditions (refer to section 3.2.3).

Guidelines for conducting sea trials, such as those referenced in this study (refs. 2, 25, 26, 27, 28), did not offer any specific information concerning the minimum required area for performing the sea trials. Usually it was stated that the area must be of adequate size for safe operation.

From the computer simulations conducted in this study, and a review of selected full-scale results (ref. 23), it is recommended that the starting position of a manoeuvre be approximately twenty ship lengths from the minimum allowable water depth contour, as illustrated in Figure 3-7. The intended trial area should also be accessible and, as far as possible, unhampered by marine traffic.

3.2.2 Approach Speed

The speed at which to execute the proposed manoeuvres varies from one manoeuvre to the next. When not specifically defined, the manoeuvres are to be executed at a particular "test" or "approach" speed as defined in reference 4. The test speed, as used in these guidelines, is defined as the speed at which a ship may be expected to navigate in areas where manoeuvres are required, and which are not restricted by insufficient water depth

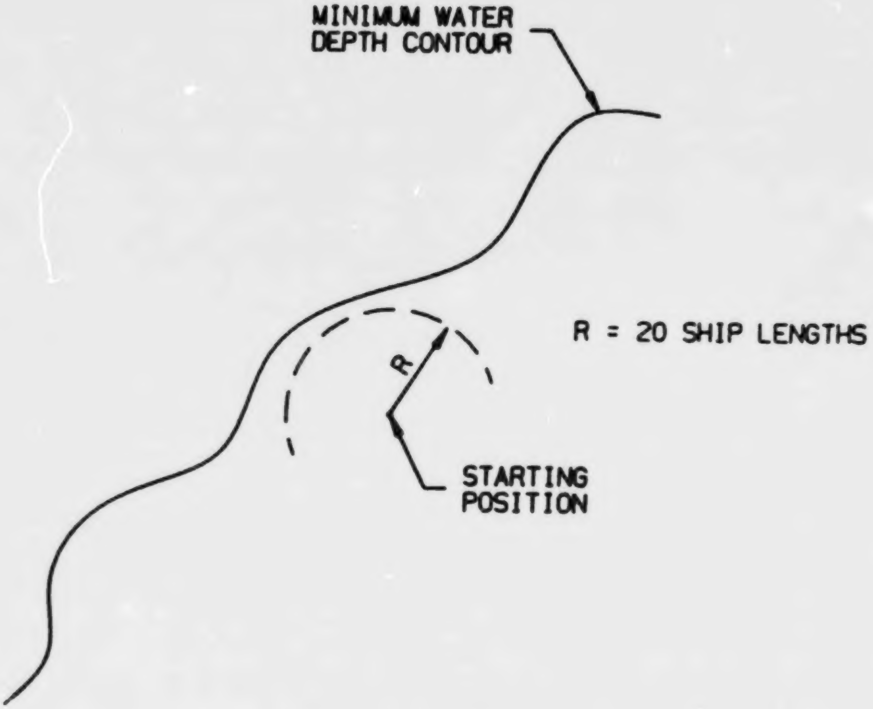


Figure 3-7: Trial Area Requirements

or channel boundaries.

The following formula is suggested in reference 4, for determining the vessel's approach speed:

$$V_T = C_B \times V_P$$

Where V_T = Test Speed (knots)
V_P = Design Speed (knots)
C_B = Block Coefficient

3.2.3 Depth of Water

The minimum depth of water recommended for the proposed trials is proportional to the ship's speed, draft and length. According to the SNAME Code for Sea Trials (ref. 25) this depth may be determined by the following formula:

$$D = \frac{5.522\,HV}{\sqrt{L_{pp}}}$$

Where D = Minimum Depth (m)
H = Trial Draft (m)
V = Approach Speed (knots)
L_{pp} = Length Between Perpendiculars (m)

Conducting trials in depths less than that calculated may result in shallow water effects, such as reduced ship speed and increased resistance, both of which would adversely affect the ship's performance.

3.2.4 Wind and Sea

Ideally, trials should be conducted in no wind and calm sea conditions. Realistically, environmental effects must be carefully considered when conducting a trial.

The effect of wind varies widely with the wind direction and fetch, the type of ship, its speed and other conditions. It is greatest for ships with high, bulky superstructures because wind speed varies exponentially with height.

The direction of the wind relative to the course is also an important factor. The work of the SNAME M-19 panel shows that the greatest resistance occurs when the relative wind blows approximately 25 degrees off the bow, however, its effect remains relatively high from 0 to 45 degrees. The wind resistance becomes zero when the relative wind is slightly abaft the beam (ref. 27).

The effects of wind described above may be largely corrected by analysis (refer to Appendix "F"). However, such calculations are approximate and, therefore, must be judiciously applied within the limits of accuracy of both the trial and formula. Furthermore, many vessels require helm to counteract the effect of wind. The resulting increased drag cannot be allowed for by any of the customary methods of analysis.

Therefore, in view of the foregoing uncertainties, it is recommended that the proposed trials be conducted under the following wind and sea conditions:

Wind $\leq$ Beaufort 4	(wind speed = 5.5 - 7.9 m/s)
Sea $\leq$ Sea State 3	(Significant wave height = 0.5 - 1.25 m)

Constant current at less than 1 m/s

The exception to this rule is during the conduct of the spiral manoeuvre, which is more adversely affected by the elements. This manoeuvre in particular should be conducted in calm seas and winds of less than 5 knots.

3.2.5 Instrumentation for Data Collection

Recording techniques proposed in several standard publications (refs. 25, 26) are unlikely to meet the accuracy requirements for manoeuvring trials. A more recent publication from Det norske Veritas (ref.29) does however provide valuable guidance. Therefore, it is recommended that the ship's recording equipment, either installed or specifically acquired for sea trials, should meet the minimum accuracy requirements stipulated by DnV as described below.

Each trial is to be considered as an independent event and, unless otherwise stated, the following data are to be continuously recorded for the duration of each manoeuvre:

i) Time
ii) Position
iii) Heading
iv) Rate of Turn
v) Speed
vi) Rudder Angle
vii) Propeller Revolutions
viii) Propeller Pitch
ix) Water Depth
x) Wind Speed and Direction Relative to the Ship

According to the recording requirements outlined by DnV (ref. 29) the record sampling frequency of an automatic recording system shall be at least 0.2 Hz (1 record per 5 seconds).

Although automatic recording is the preferred recording method, manual recording of all or some of the data may be required. The manual recording frequency shall be at least 0.05 Hz (1 record per 20 seconds). Regular sound signals or other methods should be used to ensure synchronous recording of all variables.

The accuracy requirements for each of the aforementioned trial parameters are as follows:

(i) **Time**

The chronometers shall be synchronized for consistency in reporting, and a time signal should also be provided for synchronization of all recordings. The exact time of each trial shall be identified by an obvious marking on the time record, and the time normalized to zero at the starting point.

(ii) **Position**

The ship's track shall be measured continuously for the duration of the trial. It is recommended that a microwave positioning system be used, as other systems generally have accuracy limits outside the range of accuracy of the proposed trials. To ensure proper system set-up it is recommended that the master station be located on the highest possible point on the vessel, free from interference from structure. Three slave stations should be used to provide good triangulation and to allow for the event that no suitable location is found onboard ship for the master station. As the stations are dependent on height above ground and sea level for clarity and strength of signal, the configuration of the coastline must be considered. The ship's doppler speed log may be employed if sea conditions are good and a "bottom lock" is possible, however it should only be used in conjunction with the microwave positioning system.

Accuracy: ± one ship breadth or ±10m (whichever is less)

(iii) **Heading**

The ship's heading shall be continuously recorded from the bridge compass or an equivalent system.

Accuracy: ± 0.5°

(iv) **Rate of Turn**

The ship's rate of turn shall be continuously recorded from a rate of turn indicator or by differentiating the position vector with respect to time.

Accuracy: ± 0.5°/sec.

(v) **Speed**

The ship's longitudinal and transverse speed over the ground shall be continuously recorded throughout the trial. If the ship has not been outfitted with a doppler log, the longitudinal and transverse speed should be obtained by differentiating the position vector with respect to time.

Accuracy: ± 0.25 m/sec. (± 0.5 kn.)

(vi) **Rudder Angle**

The ship's rudder angle shall be continuously recorded from the ship's rudder angle indicator or by an equivalent method.

Accuracy: ± 1°

(vii) **Propeller Revolutions**

The propeller shaft revolutions shall be continuously recorded using a direct revolution counting device.

Accuracy: ± 1.0% of design rpm

(viii) **Propeller Pitch**

For ships equipped with controllable pitch propellers, the pitch must be recorded continuously for the duration of the trial.

Accuracy: ± 5% of design full ahead pitch

(ix) **Water Depth**

The water depth shall be continuously recorded, using an echo sounder plotter. Tidal information concerning the trial area should also be recorded for depth reference.

(x) **Wind Speed and Direction Relative to the Ship**

Wind speed and direction relative to the ship shall be recorded, taking care that both anemometer and wind vane are located free of interference by structure in all directions and, therefore, not subject to wind currents and eddies from any nearby objects.

Accuracy: Anemometer: ± 0.5% m/s
Wind Vane: ± 0.5°

3.3 TRIALS CONDUCTED

The sea trials program discussed in the preceding section of this report included several trials which new vessels were recommended to perform. All of the trials in the program provide important information regarding the manoeuvrability of a vessel, however, only four of these trials were selected for the full scale tests conducted in this project. These trials were the spiral manoeuvre, turning circle manoeuvre, zigzag manoeuvre and the crash stop manoeuvre. There were two reasons for choosing these trials.

It was decided to use the four trials mentioned above because they would provide the required information, thereby keeping the project budget within reasonable limits. Secondly, the mathematical model (described in Section 5.0) and most available literature only addressed these manoeuvres.

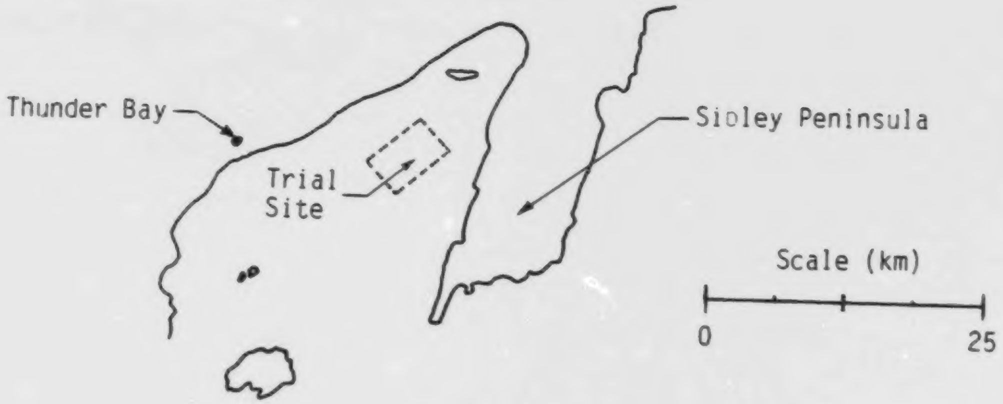
3.3.1 Selection of Vessels and Trial Sites

Research conducted during a previous project (ref. 23) demonstrated that the majority of the Canadian merchant fleet was comprised of lakers and ferries, and were therefore a logical choice for use as test examples. The vessels which were finally selected for the full scale test program were the M.V. "Algowest" and the M.V. "Atlantic Freighter".

A further advantage for choosing these vessels was that the data contained in a manoeuvring database, developed as a part of the project reported in reference 23, could be compared directly to the results of the full scale test program.

The trial sites chosen for the full scale tests met the requirement of adequate water depth (refer to section 3.2), and at the same time permitted the use of a microwave positioning system to record the vessel's track and speed during each manoeuvre. Specifically, the sites chosen were Thunder Bay Harbour for tests on the M.V. "Algowest", and an area off the east coast of Cape Breton Island for trials on the M.V. "Atlantic Freighter". Figures 3-8(a) and (b) illustrate the designated trial sites.

a) Thunder Bay



b) Cape Breton Island

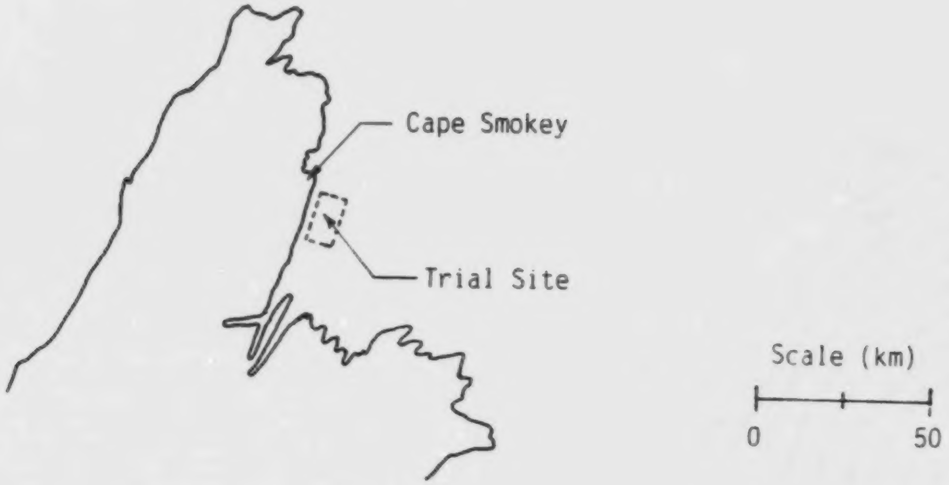


Figure 3-8: Selected Trial Sites

4.0 COST/BENEFIT ANALYSIS

4.1 GENERAL

Manoeuvring standards now cover the amount of performance data which should be recorded for display on the ship. In the future they may also cover actual performance requirements. The objectives are the same in both cases - to increase the safety of marine operations. This is done firstly by increasing the crew and/or pilot's understanding of how the ship will perform, and secondly by establishing minimum levels of ship responsiveness.

There are both real and potential costs, and real and potential benefits involved in analysis of these current and projected standards. Examples of these are:

Costs:	Increased design and construction costs Increased costs associated with tests and trials Increased costs of regulation and classification Increased operating costs/reduced revenues
Benefits:	Reduced number of accidents, costs of repairs, and loss of life Reduced insurance fees Reduced pilotage and berthing fees.

4.2 COSTS

Design costs may increase somewhat if designers are required to consider manoeuvrability in a more quantitative way than is now generally the case. Construction costs may increase if changes to hull form or steering gear characteristics are required to ensure compliance with standards. The magnitude of such costs will be proportional to the stringency of the standards, and it has been assumed here that they will not be significant if current performance levels are taken to be generally adequate. This also applies to operating costs and revenues. However, only if changes to carrying capacity result from hull modifications required to achieve compliance with standards will these standards directly influence operations.

The requirement to gather more trials data in a more systematic fashion than is now common will lead to extra costs being charged to the owner. An idea of the magnitude of these costs can be gained from the costs incurred during this project for such items as:

- equipment purchase/rental and data analysis
- labour and other operating costs
- opportunity costs.

Equipment costs are likely to reduce as the sophistication of the permanent instrumentation aboard ships increases and as full manoeuvring trials become more routine. This applies also to the effort involved in post-trial data analysis. The extra trials time involved will not however decrease, and nor will the expenses directly related to the extra time at sea - crew, fuel, etc. It is assumed that a day will in general be adequate to collect full manoeuvring data, but a two-day period has been allowed in this analysis to account for transit time, time lost due to poor weather conditions etc. These two days could also be regarded as having opportunity cost to the owner - they represent a reduction in his revenue - earning capability. Sound scheduling techniques should however reduce delays in the delivery of the ship, and opportunity costs have therefore been omitted from this analysis.

Classification/certification fees are generally linked to the expenditure of effort by regulatory bodies and classification societies in validating the ship's characteristics. Neither CCG nor societies such as Lloyds, DnV, ABS etc currently have policies in place for charging for their analysis and for confirmation of manoeuvrability. Classification inspection fees are also frequently waived or buried in annual charges. A line item for these costs has however been added to the analysis to note that they may exist in the future.

4.3 BENEFITS

Many ship casualties are linked to manoeuvring performance. Human error is often considered to be the dominant factor in incidents such as collisions and groundings - one component of such errors is often an insufficient appreciation of the manoeuvring characteristics of the ship. Also, with a higher level of manoeuvring performance available fewer situations are inherently dangerous, and more mistakes are remediable.

Table 4-1 presents a summary of Canadian marine casualty statistics, taken from reference 30. Figure 4-1 is an alternative presentation, showing primary causes of casualties. Operator error is the single most common cause of casualities. The number and ranking of collisions, groundings, striking and contacts, emphasizes their importance . Unfortunately, it is difficult to assess objectively from published data the extent to which vessel manoeuvrability influenced the individual incidents. It has therefore been somewhat arbitrarily assumed from detailed reports of well-known accidents such as the "European Gateway", "Dona Paz", "Canadian Bulker" and others that between 10 and 20 percent of collisions, groundings etc., could have been avoided or mitigated through either improved manoeuvrability or a better understanding of ship response.

The costs of a casualty include loss or damage to the ship, its cargo, its crew and passengers, and damage to the environment. Some of these costs can be identified with reasonable accuracy based on repair or replacement costs, depreciated value, incurred value, etc.

	COLLIS/N	GROUND/G	STRIKING	CONTACT	FOUNDR/G	SINKING	FIRE	EXPLOS/N	CAPSIZ/G	ICE DAMAGE	OTHER	TOTAL
Canadian	18(01)	50(01)	57(01)	62(00)	4(00)	3(01)	23(02)	3(02)	5(01)	26(00)	28(01)	279(010)
Canadian Fishing	31(02)	169(22)	60(12)	28(02)	17(12)	29(25)	111(68)	27(25)	8(04)	26(02)	136(28)	642(202)
British	0(00)	1(00)	2(00)	6(00)	0(00)	0(00)	0(00)	0(00)	0(00)	0(00)	2(00)	11(000)
U.S.A.	2(00)	3(01)	7(01)	5(00)	0(00)	0(00)	1(00)	0(00)	0(00)	0(00)	2(00)	20(002)
Panamanian	1(00)	1(00)	4(00)	14(00)	0(00)	0(00)	0(00)	0(00)	0(00)	1(00)	4(00)	25(000)
Liberian	0(00)	1(00)	6(00)	8(00)	0(00)	0(00)	1(00)	0(00)	0(00)	3(00)	1(00)	20(000)
Greek	3(00)	1(00)	6(00)	6(00)	0(00)	0(00)	1(00)	0(00)	0(00)	1(00)	0(00)	18(000)
Others	1(00)	9(01)	22(00)	17(00)	0(00)	0(00)	9(00)	0(00)	0(00)	7(00)	8(00)	73(001)
Total	56(03)	235(25)	164(14)	146(02)	21(12)	32(26)	146(70)	30(27)	13(05)	64(02)	181(29)	1088(215)
Vessel Type												
Freighter	5(00)	27(02)	58(00)	79(00)	0(00)	0(00)	10(00)	0(00)	0(00)	19(00)	16(00)	214(002)
Tanker	1(00)	8(00)	7(00)	7(00)	0(00)	0(00)	5(00)	0(00)	0(00)	9(00)	4(00)	41(000)
Tug	2(00)	8(00)	9(00)	1(00)	2(00)	2(01)	5(02)	1(01)	1(01)	1(00)	7(00)	39(005)
Barge	4(00)	7(00)	5(00)	4(00)	0(00)	0(00)	1(00)	0(00)	2(00)	0(00)	3(00)	26(000)
Fishing	32(02)	171(23)	65(13)	29(02)	17(12)	29(25)	113(68)	27(25)	8(04)	26(02)	139(28)	656(204)
Pass Ferry	6(01)	8(00)	11(00)	8(00)	0(00)	0(00)	4(00)	0(00)	1(00)	0(00)	6(00)	44(001)
Others	6(00)	6(00)	9(01)	18(00)	2(00)	1(00)	8(00)	2(01)	1(00)	9(00)	6(01)	68(003)

	CANADIAN	CDN.FISHING	BRITISH	U.S.A.	PANAMANIAN	LIBERIAN	GREEK	OTHERS	TOTAL
Freighter	94(001)	0(000)	10(000)	1(000)	24(000)	16(000)	17(000)	52(001)	214(002)
Tanker	31(000)	0(000)	0(000)	0(000)	1(000)	4(000)	1(000)	4(000)	41(000)
Tug	38(005)	0(000)	0(000)	1(000)	0(000)	0(000)	0(000)	0(000)	39(006)
Barge	23(000)	0(000)	0(000)	3(000)	0(000)	0(000)	0(000)	0(000)	26(000)
Fishing	0(000)	642(202)	0(000)	7(002)	0(000)	0(000)	0(000)	7(000)	656(204)
Pass Ferry	39(001)	0(000)	0(000)	2(000)	0(000)	0(000)	0(000)	3(000)	44(001)
Others	54(003)	0(000)	1(000)	6(000)	0(000)	0(000)	0(000)	7(000)	68(003)
Total	279(010)	642(202)	11(000)	20(002)	25(000)	20(000)	18(000)	73(001)	1088(215)
Gross Casualties	1,640,158	31,171	250,948	60,676	211,366	379,633	272,743	1,001,477	3,848,172
Tonnage(Total Loss)	2,981	(4,570)	(0)	41	(0)	(0)	(0)	6,856	(14,448)

Table 4-1: Statistical Summary of Reported Shipping Casualties in 1983

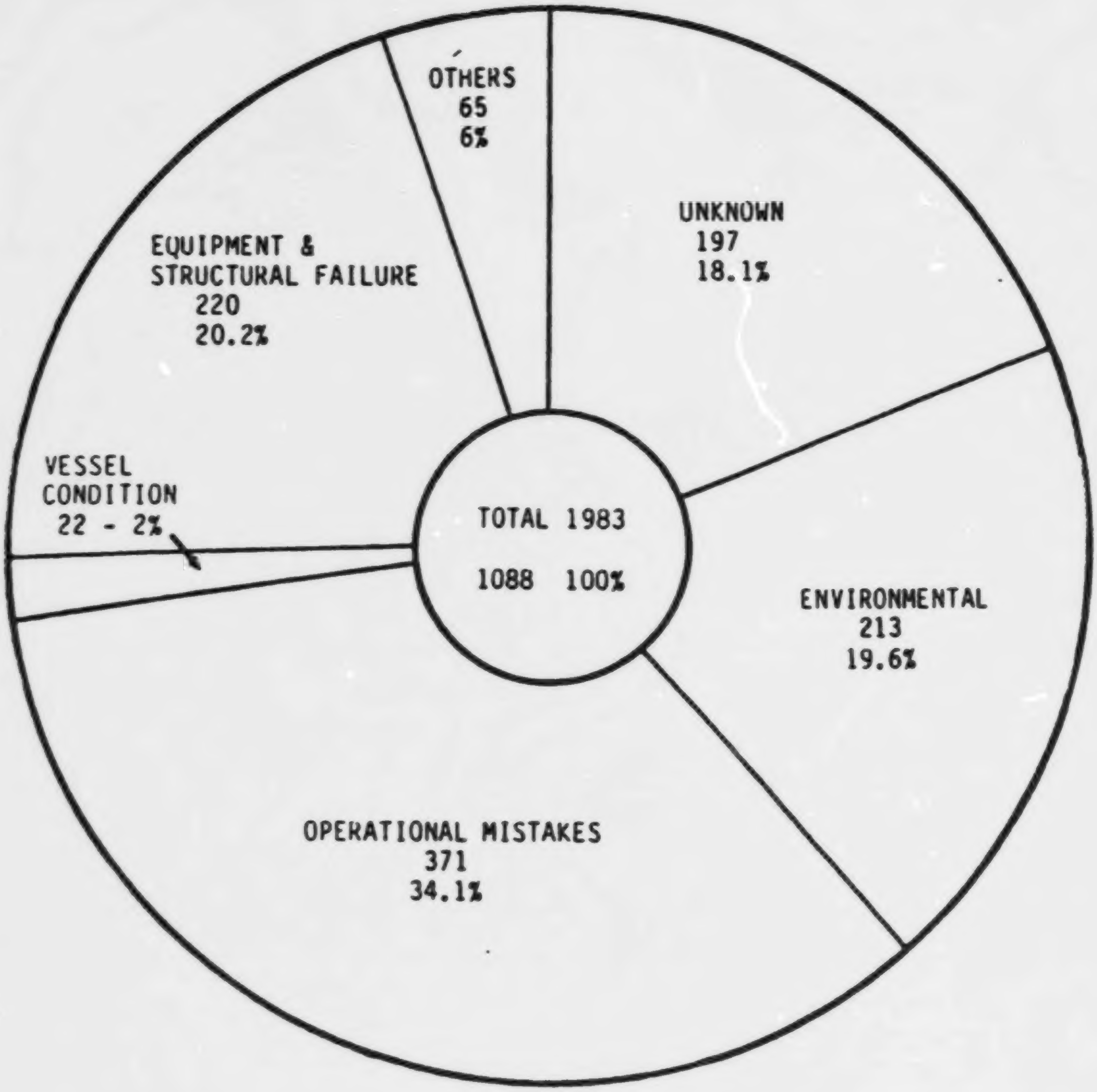


Figure 4-1: Number of Reported Casualties by Primary Attributed Cause

The costs of human death or injury are less easily determined, as are those of pollution. This last category is particularly intractable, and has not been treated specifically in the analysis.

Once it is possible to rank ships within their type on a basis of their manoeuvrability, this may become a logical justification for charging different insurance premiums reflecting their rankings. It may also be logical to tie requirements for use of pilots and tugs to the inherent characteristics of the ship. Decisions in this area are not however likely to be made rapidly, due to the large number of vested interests involved. No account has been taken of these possibilities in the analysis which follows.

4.4 ANALYSIS

The costs discussed above are evaluated on a "per ship" basis. Benefits have to be considered on a more global level, as the major benefits listed above are those associated with reducing the probability of a given type of event. Costs per ship taking the example of a representative laker, are estimated to be:

design	- $ 1,000
equipment and analysis	- $ 5,000
trials time	- $25,000
certification/classification	- $ 1,000
Total:	$32,000

From Table 4-1, 147 examples of collisions and other similar accidents to large Canadian vessels can be identified. This represented one incident for roughly every 10 Canadian vessels of greater than 500 tons (1353 vessels total in 1983). Three casualties became total losses, the others suffered varying degrees of damage as shown by the approximate percentages given in

Table 4-2. The total costs of the accidents are not known but, using the assumptions shown in Table 4-2 regarding the cost of accidents as a percentage of ship value, a weighted total value of accidents can be produced as shown in the third column.

	Percentage of casualties	Cost (% Ship Value)	Weighted Value
Total Loss	2	100	0.02
Extensive	5	20	0.01
Considerable	28	10	0.028
Minor	60	5	0.03
Unknown	5	assume 10	0.005
	100		0.093

Table 4-2: Percentages & Values of Canadian Casualties

From these figures, it can be projected that the total annual cost of this type of casualty to the Canadian fleet equals 0.1 x 0.093, or 0.9% of the total fleet value. A saving of 15% of this would equate to 0.14% of this value, or on a probabilistic basis to 0.14% of each individual new ship cost. For a 730 foot laker, valued at $40 million, this would equal $56,000.

Thus, without considering other potential benefits of improved performance and knowledge of ship behaviour, there can be seen to be a favourable balance (approximately 2:1) of benefits ($56,000) to costs ($32,000) for a vessel type of interest and importance to Canada. Similar calculations could be anticipated to produce comparable results for other types of ships.

5.0 APPLICATION OF GUIDELINES

The International Maritime Organization (IMO) issued interim guidelines (ref. 4), which recommended that estimates of the manoeuvring performance of vessels should be made during the design process. Verification of the estimates would be obtained from full-scale trails.

This section of the current study describes the algorithms, identified during the literature survey, which predict the manoeuvring performance of vessels. A discussion of the results using the selected methods is also provided.

5.1 TIME SIMULATION

Several researchers (refs. 1, 2, 5 - 12) have developed time simulation algorithms, using the equations of motion derived from the basic Newtonian equations of motion. The primary difference between the various formulations were the assumptions made regarding the hydrodynamic derivatives.

The coordinate system (see figure 5-1) and associated equations of motion used in this study, were developed in reference 1 and are as follows:

Surge: $m(\dot{u} - vr) = X_H + X_P + X_R$

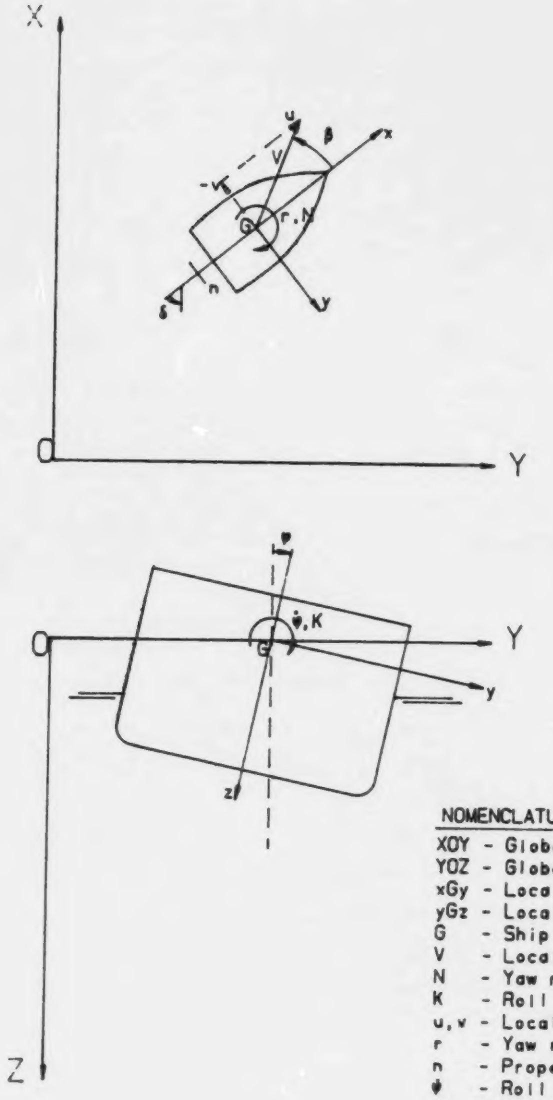
Sway: $m(\dot{v} + ur) = Y_H + Y_R$

Yaw: $I_{zz}\dot{r} = N_H + N_R$

Roll: $I_{xx}\ddot{\varphi} = K_H + K_R$

Propeller Revolution: $2 \pi I_{pp}\dot{n} = Q_E + Q_P$

where:
X_H = longitudinal hydrodynamic force acting on ship hull
X_P = propeller thrust
X_R = longitudinal component of rudder force
Y_H = lateral, hydrodynamic force acting on ship hull



NOMENCLATURE:

XOY - Global axis (horizontal plane)
YOZ - Global axis (vertical plane)
xGy - Local axis system
yGz - Local axis system
G - Ship center of gravity
V - Local ship speed
N - Yaw moment
K - Roll moment
u, v - Local components of ship speed
r - Yaw rate
n - Propeller speed
$\dot{\phi}$ - Roll rate
δ - Rudder angle
ϕ - Roll angle
β - Drift angle

Figure 5-1: Reference Coordinate System

Y_R = lateral component of rudder force
N_H = yaw moment due to hydrodynamic forces acting on ship hull
N_R = yaw moment due to rudder force
K_H = roll moment due to hydrodynamic forces acting on ship hull
K_R = roll moment due to rudder force
Q_E = main engine torque
Q_P = propeller torque
$\dot{u}$ = local, longitudinal acceleration
$\dot{v}$ = local, lateral acceleration
$\dot{r}$ = yaw acceleration
$\ddot{\varphi}$ = roll acceleration
$\dot{n}$ = propeller acceleration
u = local, longitudinal speed
v = local, lateral speed
r = yaw rate
$\dot{\varphi}$ = roll rate
n = propeller speed
β = drift angle
ψ = yaw angle
φ = roll angle
δ = rudder angle
I_{ZZ} = mass moment of inertia about local Z-axis
I_{XX} = mass moment of inertia about local X-axis
I_{PP} = moment of rotary inertia of propeller - shafting system.

Each of the terms in the equations of motion must be determined in order to find the accelerations. By integrating the accelerations with respect to time, one can determine velocities and with a further integration, displacement can be calculated. The following section of this report will discuss each of the equations of motion individually, identifying the algorithms and assumptions used to determine each of the terms in the equations.

5.1.1 Surge Equation

The surge equation from reference 1, is as follows:

$$m(\dot{u} - vr) = X_H + X_P + X_R$$

m = mass of the ship (kg)

The term "X_H" is the longitudinal, hydrodynamic force and is expressed as (ref. 1):

X_H = $-m_x\dot{u} + C_m m_y vr + X(u)$

$m_x\dot{u}$ = longitudinal component of force due to added mass of the ship in the x-direction [Newtons]
m_x = added mass of the ship in the x-direction [kg]

m_x = $0.55 \times \rho \times (B \times T)^{1.5}$ (reference 13).

ρ = density of water [kg/m^3]
B = breadth of ship [m]
T = mean draft of ship [m]
u = local acceleration of ship in the x-direction m/s^2]

$C_m m_y vr$ = longitudinal component of force due to the added mass of the ship in the y-direction [Newtons]
m_y = added mass of the ship in the y-direction [kg]

m_y = $0.5 \times \pi \times \rho \times L_{pp} \times T^2$ (reference 13)

ρ = density of water [kg/m^3]
L_{pp} = length between perpendiculars of ship [m]
T = mean draft of ship [m]
C_m = coefficient having a value between 0.50 and 0.75 (Note: $C_m = 0.62$ was used in the program)
v = local speed of the ship in the y-direction [m/s]
r = yaw rate of the ship [rad./sec]

X(u) = resistance of the ship in the x-direction, as a function of ship speed. [Newtons]

$X(u) = \dfrac{X_{res} \times u^2}{V_o^2}$ (Reference 13)

X_{RES} = initial resistance of the ship at the trial speed. This value was calculated using the method of Holtrop and Mennen (refs. 14, 15). The algorithm provided in the above references was based upon a regression analysis of both model experiments and full-scale data. [Newtons]
V_o = initial speed of the ship at the start of the manoeuvre. [m/s]
u = local speed of the ship in the x-direction. [m/s]

The thrust due to the propeller "X_P" was calculated using the expression of reference 1, with an additional factor to accommodate a twin screw ship.

$$X_p = NPROP \times (1 - t) \times \rho \times n^2 \times D^4 \times K_T$$

NPROP = number of propellers fitted to the ship
t = thrust deduction fraction which can be input directly by the user, or calculated internally by the computer using the algorithm developed by Holtrop and Mennen (refs. 14, 15).
ρ = density of water [kg/m^3]
n = propeller speed [rev./sec.]
D = propeller diameter [m]
K_T = thrust coefficient as a function of the speed of advance at the propeller.

A polynomial expression was used to determine K_T, which was derived by the Netherlands Ship Model Basin (NSMB) using the open water performance results of the Wageningen B-screw series of propellers (ref. 17). The polynomial expression is of the form:

$$K_T = \sum_{s,t,u,v} C_{s,t,u,v} \times (J)^s \times (P/D)^t \times (A_E/A_0)^u \times (Z)^v$$

$C_{s,t,u,v}$ = coefficient
J = speed of advance [m/s]
P/D = propeller pitch diameter ratio
A_E/A_0 = propeller developed blade area ratio
Z = number of propeller blades

Details of the coefficient and exponents in the above expression are in Appendix B.

The above formula for K_T was derived at a Reynolds number of 2.0×10^6, therefore a correction factor was applied to accommodate different Reynolds numbers. This factor was included in reference 14 and is as follows:

$$C_f = \Delta C_D \times 0.3 \times \frac{P \times C_{0.75} \times Z}{D^2}$$

P = propeller pitch [m]
D = propeller diameter [m]
Z = number of propeller blades
$C_{0.75}$ = chord length at a radius of $0.75 \times R$, where R is the radius of the propeller [m]
ΔC_D = difference in drag coefficient of the profile section.

Empirical formulae for $C_{0.75}$ and ΔC_D from reference 14, are given below.

$C_{0.75}$ = $2.073 \times (A_E/A_O) \times D/Z$

ΔC_D = $(2 + 4 \times (t/C)_{0.75}) \times [0.003605 - (1.89 + 1.62 \times \log (C_{0.75}/k_p))^{-2.5}]$

$(t/C)_{0.75}$ = thickness - chord length ratio

$(t/C)_{0.75}$ = $(0.0185 - 0.00125 \times Z) \times D/C_{0.75}$

k_p = propeller blade surface roughness

k_p = 0.00003 [m]

The final expression for K_T which was used in the manoeuvring model is:

$$K_T = (K_T)_{\text{B-series}} + C_f$$

The B-screw series of propellers is representative of most standard merchant vessel propellers and was therefore considered to be a reasonable approximation for the manoeuvring model (refs. 1, 14). It should be noted that the user may substitute specific propeller data by simply replacing the subroutine.

The last component of the longitudinal force is "X_R", which is the rudder force acting in the x-direction. From reference 1, the expression for "X_R" is:

$$X_R = -F_N \sin \delta$$

δ = applied rudder angle [radians]
F_N = rudder normal force [Newtons]

$$F_N = 0.5 \times \rho \times \frac{6.13\lambda}{\lambda + 2.25} \times A_R \times V_R^2 \times \sin \alpha_R$$

ρ = density of water [kg/m^2]
λ = rudder aspect ratio
A_R = profile area of the rudder [m^2]

V_R = effective rudder inflow speed [m/s]
α_R = effective rudder inflow angle [radians]

Both the inflow speed "V_R" and the inflow angle "α_R" are affected by the interaction between the propeller and the hull. Reference 1 contains several parameters which attempt to model the complex flow phenomenon occurring at the rudder. These parameters are described in detail in this report for three reasons.

Firstly, the rudder force is a key element of the manoeuvring simulation, therefore, a complete description is warranted within this document. Secondly, a typographical error was discovered in reference 1 which requires clarification, and in addition, an expression from reference 13 was substituted into the model of reference 1. Finally, German and Milne added an option to allow for twin screw ships with twin rudders directly behind the propellers.

From reference 1, the expression for the rudder inflow speed "V_R" is:

$$V_R = V \times (1-w_R) \times [1 + K_2 \times g(s)]^{0.5}$$

V = speed of ship [m/s]
K_2 = 1.065 for port rudder
= 0.935 for starboard rudder
W_R = effective rudder wake fraction

$$W_R = W_{RO} \times \exp (K_1 \times \beta_p{}^2)$$

W_{RO} = rudder wake fraction in the straight running condition
K_1 = -4.0
β_p = inflow angle at the propeller [radians]

β_p = $\beta + X'pr'$ (note that this formula was printed incorrectly in reference 1)
β = drift angle [radians]
$X'p$ = non-dimensional position of the propeller
= Xp/Lpp

Xp = longitudinal position of the propeller with respect to the ship's centre of gravity [m]

L_{pp} = length between perpendiculars [m]
r' = non-dimensional turning rate

$r' = \frac{r \times L_{pp}}{V}$

r = yaw rate of ship [rad/sec]

$g(s) = \eta \times \kappa \times [2 - (2-\kappa) \times s] \times s/(1 - s)^2$

$\eta = D/H$

D = propeller diameter [m]
H = rudder height [m]

$\kappa = 0.6 \times (1 - W_P)/(1 - W_R)$

W_P = effective propeller wake fraction

$W_p = W_{Po} \times \exp(K_1 \times \beta_p{}^2)$

W_{po} = propeller wake fraction in straight running condition

s = propeller slip ratio

$s = 1-u \times (1 - W_p)/(nP)$

n = propeller speed [rev/sec]
u = ship speed in the local x-direction [m/s]
P = propeller pitch [m]

The effective rudder inflow angle "α_R" was obtained from reference 13 and is expressed as:

$\alpha_R = \delta - \gamma\beta'_R$

δ = applied rudder angle [radians]
β'_R = rudder inflow angle [radians]

$\beta'_R = \beta - 2 \times X'_R \times r'$

X'_R = non-dimensional position of the rudder

$X'_R = X_R/L_{pp}$

X_R = longitudinal position of the rudder centre of gravity with respect to the ship's centre of gravity [m]
γ = flow rectification coefficient

$\gamma = C_p \times C_s$

C_p = propeller flow rectification coefficient

$C_p = 1/[1 + 0.6 \times \eta \times (2 - 1.4 \times s) \times s/(1 - s^2]^{0.5}$

C_s = ship hull flow rectification coefficient

$C_s = 0.45 \times \beta'_R$ for $\beta'_R \leq 1.11$

$C_s = 0.5$ for $\beta'_R > 1.11$

As was previously mentioned, German and Milne has incorporated an approximation to permit the modelling of twin screw ships with twin rudders. The user inputs the dimensions of one rudder, as required for single rudder ships, and the program calculates the normal rudder force "F_N" using the relationships outlined in the preceding pages. Based on German & Milne's experience, a factor of 1.5 was applied to the normal force to simulate ships with twin rudders. For twin screw ships fitted with twin rudders, the expression for the normal force is:

$F_N = 1.5 \times (F_N)_{single}$

$(F_N)_{single}$ = rudder normal force calculated using the dimensions of a single rudder, and the relationships stated in the preceding pages.

All of the parameters in the surge equation:

$$m(\dot{u} - vr) = X_H + X_P + X_R$$

have now been quantified. The manoeuvring model requires that the above equation be rewritten such that the longitudinal acceleration "$\dot{u}$" is the only term on the left hand side. Rewriting the above equation in the appropriate form:

$\dot{u}$ = $[(C_m \times m_y + m) \times v \times r + X(u) + X_P + X_R]/(m + m_x)$

5.1.2 Sway Equation

The sway equation from reference 1 is:

$$m(\dot{v} + ur) = Y_H + Y_R$$

m = mass of the ship [kg]

The term "Y_H", is the lateral hydrodynamic force acting on the ship's hull and is defined by the following relationship (ref.1):

$$Y_H = -m_y\dot{v} - m_x ur + Y_{HO}(v,r) + Y_{H1}(v,r,\varphi)$$

$m_y\dot{v}$ = lateral component of force due to the added mas of the ship in the y-direction [Newtons]
m_y = added mass of the ship in the y-direction [kg]
$\dot{v}$ = local acceleration of the ship in the y-direction [m/sec^2]

$m_x ur$ = lateral component of force due to the added mass of the ship in the x-direction [Newtons]
u = local speed of the ship in the x-direction [m/s]
r = yaw rate [rad./sec]
$Y_{H1}(v,r,\varphi)$ = lateral force due to the roll effect [Newtons]
= 0.

$Y_{HO}(v,r)$ = lateral hydrodynamic force [Newtons]
$Y_{HO}(v,r) = 0.5\rho LTV^2[Y'_v v' + Y'_r r' + Y'_{vv} v'|v'| + Y'_{vr} v'|r'| + Y'_{rr} r'|r'|]$

ρ = density of water [kg/m^3]
L = length between perpendiculars [m]
T = mean draft of the ship [m]
V = ship speed [m/s]
v' = non-dimensional local speed of ship in the y-direction
v' = v/V
r' = non-dimensional turning rate of ship

r' = $r \times L/V$

Y'_v = non-dimensional, linear, hydrodynamic derivative of lateral force with respect to sway speed.

$$Y'_v = -\left(\frac{\pi k}{2} + 1.4 \frac{C_B \times B}{L}\right) \times \left(1 + \frac{2 \times \tau}{3 \times T}\right)$$

k = 2 T/L
C_B = block coefficient
B = breadth of the ship [m]
T = mean draft of the ship [m]
τ = trim of the ship [m]

$$\tau = T_{aft} - T_{fwd}$$

T_{aft} = draft aft [m]
T_{fwd} = draft forward [m]
Y'_r = non-dimensional, linear, hydrodynamic derivative of lateral force with respect to yaw rate

$$Y'_r = \frac{\pi \times k}{4} \times \left(1 + 0.8 \times \frac{\tau}{T}\right)$$

Y'_{vv} = non-dimensional, non-linear, hydrodynamic derivative of lateral force with respect to the square of sway speed

$$Y'_{vv} = -6.49 \times (1 - C_B) \times T/B + 0.0795$$

Y'_{vr} = non-dimensional, non-linear, hydrodynamic derivative of lateral force with respect to the product of sway speed and yaw rate

$$Y'_{vr} = 1.82 \times (1 - C_B) \times T/B - 0.447$$

Y'_{rr} = non-dimensional, non-linear, hydrodynamic derivative of lateral force with respect to the square of the yaw rate

$$Y'_{rr} = -0.4664 \times (1 - C_B) \times T/B$$

The second term in the sway equation is "Y_R", which is lateral component of the rudder force. The relationship for "Y_R" from reference 1 is:

$$Y_R = -(1 + a_H) \times F_N \times \cos \delta$$

δ = applied rudder angle [radians]
F_N = rudder normal force [Newtons]
a_H = coefficient estimated from experimental results

a_H = 0.627 x C_B - 0.153 (note this relationship was stated in reference 13)

With both terms of the sway equation defined, the equation can be rewritten in the form:

$$\dot{v} = [-(m + m_x) \times u \times r + Y_{H0}(v,r) + Y_{H1}(v,r,\varphi) + Y_R]/(m + m_y)$$

5.1.3 Yaw Equation

The yaw equation in reference 1 is stated as:

$I_{zz}\dot{r}$ = $N_H + N_R$

I_{zz} = mass moment of inertia of the ship about the vertical z-axis [kg-m^2]

I_{zz} = $k^2_{zz} \times m$

k_{zz} = radius of gyration about the z-axis [m]
m = mass of the ship [kg]
$\dot{r}$ = yaw acceleration [rad/s^2]

Estimates of the radii of gyration "k_{zz}" were obtained from reference 18, in which the following relationships were derived from an analysis of several ship types.

k_{zz} = $C \times (L^2 + B^2)^{0.5}$

L = length between perpendiculars [m]
B = breadth of ship [m]

C = 0.2891 for a RoRo type vessel

= 0.2804 for a LASH type vessel

= 0.2672 for a LNG type vessel

For other vessel types:

k_{zz} = 0.25 x L

The first term in the yaw equation, "N_H", is the hydrodynamic moment acting on the ship's hull and is defined by the expression:

$$N_H = -J_{zz} \times \dot{r} + N_{HO}(v,r) + N_{H1}(v,r,\varphi) + [Y_{Ho}(v,r) + Y_{H1}(v,r,\varphi)] \times X_{mid}$$

J_{zz} = added mass moment of inertia about the z-axis [kg - m^2]

J_{zz} = $\pi \times \rho \times L^3 \times T^2/24$ (from reference 13)

ρ = density of water [kg/m^3]
L = length between perpendiculars [m]
T = mean draft of ship [m]

$N_{HO}(v,r)$ = hydrodynamic moment [N-m]

$N_{HO}(v,r)$ = $0.5\rho L^2 T V^2 [N'_v v' + N'_r r' + N'_{vvr} v'^2 r' + N'_{vrr} v' r'^2 + N'_{rr} r' |r'|]$

V = speed of the ship [m/s]
v' = non-dimensional local speed of ship in the y-direction
r' = non-dimensional yaw rate of the ship
N'_v = non-dimensional, linear, hydrodynamic derivative of yaw moment with respect to sway speed.

N'_v = $-k \times (1 - (0.27/LBETA) \times \tau/T)$

k = $2 \times T/L$

LBETA = $k/ (\pi \times k/2 + 1.4 \times C_B \times B/L)$
τ = trim of the ship [m]
B = breadth of the ship [m]
C_B = block coefficient

$N'r$ = non-dimensional, linear, hydroynamic derivative of yaw moment with respect to yaw rate
$N'r$ = $-(0.54 \times k - k^2) \times (1 + 0.3 \times \tau/T)$

N'_{vvr} = non-dimensional, non-linear, hydrodynamic derivative of yaw moment with respect to the product of sway speed squared and yaw rate

$$N'_{vvr} = -\left[3.25 \times \frac{C_B \times B}{L} - 0.35 + 10^{-7} \times \left(\frac{L}{(C_B \times B)}\right)^6\right]$$

N'_{vrr} = non-dimensional, non-linear, hydrodynamic derivative of yaw moment with respect to the product of the sway speed and square of the yaw rate.

N'_{vrr} = $0.444 \times C_B \times T/B - 0.064$

N'_{rr} = non-dimensional, non-linear, hydrodynamic derivative of yaw moment with respect to the yaw rate squared.

= $-\left(1.7 \times \left|\frac{C_B \times B}{L} - 0.157\right|^{1.5} + 0.01\right)$

$N_{H1}(v,r,\varphi)$ = hydrodynamic moment due to the roll effect [N-m]

= $0.5\rho L^2TV^2[N'_{\varphi}\varphi + N'_{v\varphi}v'|\varphi| + N'_{r\varphi}r'|\varphi|]$

N'_{φ} = non-dimensional, hydrodynamic derivative of yaw moment with respect to the roll angle

N'_{φ} = 0.0076

$N'_{v\varphi}$ = non-dimensional, hydrodynamic derivative of yaw moment with respect to the product of sway speed and roll angle.

$N'_{v\varphi}$ = $1.716 \times N'_v$

$N'_{r\varphi}$ = non-dimensional, hydrodynamic derivative of yaw moment with respect to the product of yaw rate and roll angle.

$N'_{r\varphi}$ = $2.36 \times N'_r$

$Y_{H0}(v,r)$ = same definition as per "Y_H"
$Y_{H1}(v,r,\varphi)$ = same definition as per "Y_H"
X_{mid} = longitudinal position of midships with respect to the ship's centre of gravity [m]

The second term in the yaw equation, "N_R", is the yaw moment due to the rudder force. The formula quoted in reference 1 is:

N_R = $-(1 + a_H) \times X_R \times F_N \cos\delta$

δ = applied rudder angle [radians]
F_N = rudder normal force [Newtons]

X_R = longitudinal position of the rudder centre of gravity with respect to the ship's centre of gravity [m]

a_H = coefficient determined from experimental tests (see definition in the sway equation).

The yaw equation can now be rewritten in the form:

$$\dot{r} = \{N_{HO}(v,r)+N_{H1}(v,r,\varphi)+[Y_{HO}(v,r)+Y_{H1}(v,r,\varphi)]xX_{mid}+N_R\}/(I_{zz}+J_{zz})$$

which is the format required for the manoeuvring model.

5.1.4 Roll Equation

Research conducted by Inoue (ref.1) indicated that for certain ships, such as high speed container ships, it was necessary to include the roll effect to simulate the manoeuvring motion of these vessels. The use of the roll equation is not mandatory for ships which do not experience large heel angles during various manoeuvres. However, by including the equation, the model has a wider range of applicability and will predict small roll angles for ships (e.g. lakers, ferries) which would normally experience small angles of heel.

The roll equation from reference 1 is:

$I_{xx}\ddot{\varphi}$ = $K_H + K_R$

I_{xx} = mass moment of inertia of the ship about the longitudinal, x-axis [kg-m^2]

I_{xx} = $k^2_{xx} \times m$

k_{xx} = radius of gyration about the x-axis [m]

m = mass of the ship [kg]
$\ddot{\varphi}$ = roll acceleration [rad/s^2]

The roll radius of gyration, "k_{xx}", was estimated using empirical relationships derived in reference 18. These formulae are:

$$k_{xx} = C \times (B^2 + D^2)^{0.5}$$

B = ship breadth [m]
D = ship depth [m]
C = 0.2939 for a RoRo type vessel
= 0.3177 for a LASH type vessel
= 0.2979 for a LNG type vessel

For other vessel types:

$$k_{xx} = \left[\frac{(B^2 \times C_{wp}{}^2)}{(11.4 \times C_B)} + \frac{(D^2)}{(12)} \right]^{0.5}$$

C_{wp} = waterplane coefficient
C_B = block coefficient

On the right hand side of the roll equation, the first term "K_H" represents the roll moment due to the hydrodynamic forces acting on the hull, and is expressed by:

$$K_H = -J_{xx} \times \varphi - N(\varphi) - W \times GZ(\varphi) - Y_H \times Z_H$$

J_{xx} = added mass moment of inertia about the x-axis [kg-m^2]
J_{xx} = $0.013 \times \rho \times C_B \times L \times B^3 \times T \times (1 + 0.037 \times B/T)^2)$ (reference 13)
ρ = density of water [kg/m^3]
C_B = block coefficient
L = length between perpendiculars [m]
B = breadth [m]
T = mean draft [m]

$N(\varphi)$ = roll damping moment [N-m]

$N(\varphi)$ = $0.214 \times k_{xx} \times m \times (g \times GM)^{0.5} \times$

m = mass of the ship [kg]
g = gravitational acceleration constant [m/s^2]
φ = roll angle speed [rad./sec.]
GM = metacentric height [m]

The metacentric height can be input directly by the user if it is known, or it will be estimated by the computer using the relationship (ref. 13):

$$GM = (-0.09 + 0.0965 \times C_B + 0.0548 \times B/T) \times B$$

The next term in the equation for "K_H" is:

$W \times GZ(\varphi)$ = restoring moment [N-m]
$W \times GZ(\varphi)$ = $m \times g \times GM \times \varphi$ (reference 13)

m = mass of the ship [kg]
φ = roll angle [radians]

$Y_H \times Z_H$ = roll moment due to the lateral, hydrodynamic force [N-m]

Y_H = lateral, hydrodynamic force [Newtons]; refer to sway equation for a complete definition

Z_H = distance between VCG of the ship and the point at which the hydrodynamic force is assumed to act

Z_H = VCG - T/2 (reference 13)

To allow for the influence of the rudder force on the total roll angle, the term K_R was included in the roll equation. From reference 1:

$$K_R = (1 \times a_H) \times Z_R \times F_N \times \cos \delta$$

a_H = coefficient determined from experimental results (see definition in the sway equation)
Z_R = vertical distance between the centre of gravity of the ship and the rudder [m]
F_N = rudder normal force [Newtons]
δ = applied rudder angle [radians]

The roll equation can now be rewritten in the following form:

$$\ddot{\varphi} = (-N(\dot{\varphi}) - W \times GZ(\varphi) - Y_H \times Z_H + K_R)/(I_{xx} + J_{xx})$$

5.1.5 Propeller Equation

During full scale trials, the propeller speed changes due to the variation of the main engine torque and propeller torque. According to Inoue (ref. 1), these changes should be modelled because of their effect on the propeller thrust and the rudder forces.

The final equation of motion (ref. 1) represents the instantaneous propeller acceleration, as the summation of the main engine torque and propeller torque.

$$2 \times \pi \times I_{pp} \times \dot{n} = Q_E + Q_p$$

I_{pp} = virtual mass moment of inertia of the propeller, which includes the added mass moment of inertia [kg - m^2]

I_{pp} = $20 \times D_p^5$ (reference 13)

D_p = diameter of the propeller [m]
$\dot{n}$ = propeller acceleration [rev/s^2]

The main engine torque "Q_E", was modelled for two types of propulsion systems. For a steam turbine arrangement:

Q_E = $SHP/(2 \times \pi \times n)$ (reference 1)

SHP = shaft horsepower [Watts]

n = propeller speed [rev/sec]

For a slow speed diesel engine arrangement, the torque is essentially constant and was modelled as:

Q_E = $|(Q_p)_o|$ (reference 13)

$(Q_p)_o$ = torque of the propeller at the initial RPM and ship speed [N-m]

The propeller torque was calculated using the expression:

$$Q_p = -\rho n^2 D^5 K_Q$$

ρ = density of water [kg/m^3]
n = propeller speed [rev/sec]
D = propeller diameter [m]
K_Q = propeller torque coefficient as a function of the speed of advance at the propeller

Similar to the thrust coefficient, "K_T", which was calculated using a polynomial expression derived by NSMB (ref. 17) for the B-screw series, the torque coefficient polynomial was of the following form:

$$K_Q = \sum_{s,t,u,v} C_{s,t,u,v} \times (J)^s \times (P/D)^t \times (A_E/A_o)^u \times (Z)^v$$

$C_{s,t,u,v}$ = coefficient
J = speed of advance [m/o]
P/D = propeller pitch diameter ratio
A_E/A_o = propeller developed blade area ratio
Z = number of propeller blades

The coefficients and exponents for the above formula (ref. 17) are given in Appendix B.

The correction factor which must be applied to "K_T" for Reynolds numbers other than 2.0×10^6 is given by:

$$C_f = \frac{\Delta C_D \times 0.25 \times C_{0.75} \times Z}{D} \quad \text{(reference 14)}$$

Z = number of propeller blades
D = propeller diameter [m]
$C_{0.75}$ = chord length at a radius of $0.75 \times R$, where R is the radius of the propeller [m]
ΔC_D = difference in the drag coefficient of the profile section

Empirical formulae for $C_{0.75}$ and ΔC_D from reference 14, are provided in section 5.1.1 of this report.

The final expression for K_Q is:

$$K_Q = (K_Q)_{B\text{-series}} - C_f$$

The final form of the propeller equation which was used in the manoeuvring model is:

$$\dot{n} = (Q_E + Q_p)/(2 \times \pi \times Ipp)$$

5.2 EMPIRICAL ESTIMATES

During the literature survey, which was the first task performed for this project, empirical estimates of the turning circle parameters and the head reach during a crash stop manoeuvre were identified (refs. 2,3). The empirical formulae, which are discussed in the following sections of this report, were incorporated into the main computer program as separate subroutines. Detailed descriptions of the subroutines are contained in the User Manual (ref. 16).

5.2.1 Turning Circle Estimate

Lyster, et.al (ref. 3) compiled a database consisting of published full-scale results and model results, obtained from turning circle manoeuvres. The trials included tests of twin screw and single screw ships, representing a range of sizes, approach speeds and applied rudder angles.

A regression analysis was performed by Lyster on the raw data, which resulted in two sets of empirical equations; one for the single screw and one for the twin screw ships. These equations predicted the tactical diameter, steady turning diameter, steady turning speed, advance, and transfer for a ship during the manoeuvre. The regression analysis also provided the standard deviation for each of the parameters.

For the twin screw ships, the following equations were derived (ref.3).

$$\frac{STD}{L} = 0.727 - \left(\frac{197 \times C_B}{|\delta|}\right) + \left(\frac{4.65 \times B}{L}\right) + \left(\frac{41.0 \times Trim}{L}\right) + \left(\frac{188}{|\delta|}\right)$$

$$- \left(\frac{218 \times S_P \times Ch \times (NR - 1)}{L \times T}\right) + \left(\frac{3.20 \times V_A}{\sqrt{L}}\right) + \left(\frac{25.56 \times A_B}{L \times T}\right) \quad (\sigma = 0.271)$$

$$\frac{TD}{L} = 0.140 + \left(\frac{1.00 \times STD}{L}\right) \quad (\sigma = 0.066)$$

$$\frac{Ad}{L} = 1.10 + \left(\frac{0.514 \times TD}{L}\right) \quad (\sigma = 0.188)$$

$$\frac{Tr}{L} = -0.357 + \left(\frac{0.531 \times TD}{L}\right) \quad (\sigma = 0.129)$$

$$\frac{V_T}{V_A} = 0.543 + \left(\frac{0.028 \times TD}{L}\right) \quad (\sigma = 0.166)$$

For the single screw ships, the following equations were derived (ref. 3).

$$\frac{STD}{L} = 4.19 - \left(\frac{203 \times C_B}{\delta}\right) + \left(\frac{47.4 \times Trim}{L}\right) - \left(\frac{13.0 \times B}{L}\right) + \left(\frac{194}{\delta}\right)$$

$$- \left(\frac{35.8 \times S_P \times Ch \times (ST - 1)}{L \times T}\right) + \left(\frac{3.82 \times S_P \times Ch \times (ST - 2)}{L \times T}\right) + \left(\frac{7.79 \times A_B}{L \times T}\right)$$

$$+ \left(0.70 \times \frac{(T - 1)}{(T_L)} \times \frac{(\delta)}{(|\delta|)} \times (ST - 1)\right) \quad (\sigma = 0.244)$$

$$\frac{TD}{L} = \left(\frac{0.910 \times STD}{L}\right) + \left(\frac{0.424 \times V_A}{\sqrt{L}}\right) + 0.675 \quad (\sigma = 0.111)$$

$$\frac{Ad}{L} = \left(\frac{0.519 \times TD}{L}\right) + 1.33 \quad (\sigma = 0.162)$$

$$\frac{Tr}{L} = \left(\frac{0.497 \times TD}{L}\right) - 0.065 \quad (\sigma = 0.170)$$

$$\frac{V_T}{V_A} = \left(\frac{0.074 \times TD}{L}\right) + 0.149 \quad (\sigma = 0.185)$$

The nomenclature applicable to both sets of equations is as follows:

ST = type of stern of single screw ships
= 1 for closed stern
= 2 for open water stern
NR = number of rudders
L = Length between perpendiculars (feet)
C_B = block coefficient
δ = rudder angle (degrees), positive if angle is to port, and negative if to starboard
B = beam (feet)
A_B = submerged bow profile area (sq. feet), considered positive when projecting forward of the fore perpendicular, and negative when corresponding to "cutaway" as in the case of a conventional raked stem.
T = mean trial draft (feet)
T_L = mean design draft (feet)
Trim = trim (feet), considered positive if trim by stern and negative if trim by bow
V_A = velocity of approach (knots)
V_T = velocity on steady turn (knots)
S_P = span of rudder (feet)
Ch = chord of rudder (feet)
σ = standard deviation
STD = steady turning diameter (feet)
TD = tactical diameter (feet)
Ad = advance (feet)
T_R = transfer (feet)

It is important to note that the preceding equations were developed in imperial units. The input data required by the computer program, as described in the User Manual (ref. 16), is in SI units. This input data is later converted internally, before it is used in the equations.

The applicability of the preceding equations is limited to the range and distribution of the data contained in the database used by Lyster.

Table 5-1 summarizes the range of data which was used to derive the preceding equations. This table has been included in the computer program, and if one or more of the input parameters falls outside the range of the database, a warning message will be printed on the output file.

PARAMETER	SINGLE SCREWS		TWIN SCREWS	
	MINIMUM	MAXIMUM	MINIMUM	MAXIMUM
L (ft)	180	1080	250	740
C_B	0.56	0.87	0.42	0.62
δ (deg.)	10	45	10	35
B/L	0.11	0.18	0.06	0.20
Trim/L	0	0.05	-0.01	0.03
$S_p Ch/LT$	0.01	0.04	0.01	0
A_B/LT	-0.11	+0.04	-0.10	0
V_A/ L	0.20	1.0	0.25	2.2
T/T_L	0.50	1.0	0.60	1.1

L =length between perpendiculars
C_B = block coefficient
δ = rudder angle (negative if to starboard)
B = breadth moulded in feet
Trim = trim of ship in feet (negative if trim by the bow)
S_p = span of rudder in feet
Ch = chord of rudder in feet
T = mean trial draft in feet
T_L = design load draft in feet
V_A = approach speed in knots
A_B = submerged bow profile area in ft.^{2}, considered positive when projecting forward of the fore perpendicular and negative when corresponding to "cutaway" as in the case of a conventional raked stem

Table 5-1: Limits of the Database (ref. 3)

5.2.2 Crash Stop Estimate

The controllability of a ship during the crash stop manoeuvre is altered significantly due to the reduction of ship speed. The loss of ship speed decreases the velocity of flow over the ship and also over the rudder. In addition, the flow over the rudder will decrease even further if the propeller is turning in reverse.

Various sources were reviewed (refs. 2, 13, 19, 20, 21 and 22) during the literature survey to obtain a method for predicting a ship's behaviour during the crash stop manoeuvre. The empirical relationship stated in both references 2 and 13 was chosen because of its simplicity and wide range of applicability. The other references were either too specific (refs. 20, 21), impractical for direct application (ref. 22), or did not directly address the topic of predicting crash stop behaviour (ref. 19). The relationship selected is:

$$S = \frac{106.2 \times V_0^2}{T_1/\Delta} - \frac{34.3 \times V_0^2 \times R_0/\Delta}{(T_1/\Delta)^2} + 16.9 \times V_0$$

Where S = head reach (feet)
V_0 = initial ship speed (knots)
R_0 = initial ship resistance at the speed V_0 (pounds)
T_1 = maximum astern thrust (pounds)
Δ = ship displacement (tons)

The computer program requires the input data to be in SI units, and automatically converts the information for use in the crash stop formula. A full description of the software is provided in reference 16.

5.3 APPLICATION OF MANOEUVRING MODEL

The mathematical model presented in the previous sections of this report was used to estimate the manoeuvring performance of the laker M.V. "Algowest" and ferry M.V. "Atlantic Freighter". Both of these vessels were used for the full scale trials portion of this study (refer to section 3.3) which provided the reference data required to validate the model.

5.3.1 Application to M.V. "Algowest"

Recognizing that a large portion of the Canadian merchant fleet is comprised of lakers, it was decided that this ship type should be analyzed during the course of this study. Furthermore, an earlier project (ref. 23) illustrated that there was a wide scatter of trials results data, for similar ships within the laker type of vessel. Therefore, further analysis was warranted.

Table 5-2 lists the basic input data of the laker (M.V. "Algowest") chosen for the computer analysis. This laker was tested in a ballast condition and a fully loaded condition.

Parameter Description	Value
Length between perpendiculars	218.80 m
Breadth	23.12 m
Mean Draft (Loaded Condition)	7.93 m
Mean Draft (Ballast Condition)	5.03 m
Depth	14.18 m
Mass (Loaded Condition)	35640 t
Mass (Ballast Condition)	21900 t
Block Coefficient	0.88
Midship Section Coefficient	0.996
Waterplane coefficient	0.914
Shaft Horsepower	5400 kW
Rudder Area	25.10 m^2
Rudder Aspect Ratio	1.57
Propeller Diameter	5.70 m
Propeller Pitch/Diameter Ratio	0.96
Expanded Blade Area Ratio	0.50

Table 5-2: Basic Laker Parameters

The complete data files for the laker in the two conditions required to run the computer program, are provided in Appendix "D" in addition to the complete sets of results, and a listing of the program.

5.3.2 M.V. "Algowest" Turning Circle Results

The M.V. "Algowest" completed turning circles to port and starboard using a rudder angle of 35 degrees. As mentioned previously these tests were conducted in ballast and fully loaded conditions, therefore, the computer simulations were also executed for these conditions. In addition to the computer simulations, the turning circle parameters contained in the manoeuvring database (ref. 23) were obtained to provide a further comparison (refer to Section 5.4.4). Results for the turning circle manoeuvre are presented in Tables 5-3 and 5-4, and the output from the computer simulation is included in Appendix D.

Figures 5-2 and 5-3 illustrate the ship's track during the turning circle manoeuvre, as predicted by the computer and measured during full-scale trials. Figure 5-4 presents a plot of RPM, yaw angle and ship speed versus time for the computer simulations. During the full-scale trials, it was observed that the RPM remained constant. The final ship speed for both test conditions is recorded in Tables 5-3 and 5-4.

5.3.3 M.V. "Algowest" Zigzag Results

The full scale trials conducted on the M.V. "Algowest" included $10^o/10^o$ and $20^o/20^o$ zigzag manoeuvres in the ballast and fully loaded conditions. All manoeuvres were performed within the range of the microwave positioning system (see Section 3.3.1) with the exception of the $10^o/10^o$ zigzag in the ballast condition, and one of the $20^o/20^o$ trials also in the ballast condition. For these manoeuvres, the non-dimensional reach and overshoot width of

PARAMETER DESCRIPTION	TIME SIMULATION	EMPIRICAL ESTIMATE	FULL SCALE RESULTS	
			TRIAL 1	TRIAL 2
Steady Turning Speed (knots)	6.06 (6.91)*	3.87 (4.49)	5.1 (4.9)	4.7 (5.4)
Non-dimensional ** Advance	2.71 (2.84)	2.87 (3.28)	3.27 (3.16)	2.78 (3.23)
Non-dimensional Transfer	1.26 (1.36)	1.41 (1.81)	1.5 (1.57)	1.5 (1.63)
Non-dimensional Tactical Diameter	3.13 (3.34)	2.97 (3.77)	3.09 (3.31)	3.13 (3.35)
Non-dimensional Steady Turning Diameter	2.38 (2.70)	2.34 (3.21)	2.4 (2.61)	2.43 (2.76)

*( ) indicates values for port turn
** values are non-dimensionalized by Lpp

Table 5-3: M.V. "Algowest" Turning Circle Manoeuvre Results - Loaded Condition

PARAMETER DESCRIPTION	TIME SIMULATION	EMPIRICAL ESTIMATE	FULL SCALE RESULTS	
			TRIAL 1	TRIAL 2
Steady Turning Speed (knots)	8.50 (9.30)*	5.23 (5.97)	6.4 (5.8)	7.4 (6.3)
Non-dimensional ** Advance	2.72 (2.86)	3.22 (3.63)	3.19 (2.98)	3.21 (3.0)
Non-dimensional Transfer	1.38 (1.49)	1.74 (2.14)	1.63 (1.53)	1.46 (1.49)
Non-dimensional Tactical Diameter	3.37 (3.66)	3.64 (4.44)	3.59 (3.32)	3.31 (3.29)
Non-dimensional Steady Turning Diameter	2.75 (3.13)	3.04 (3.92)	2.73 (2.79)	2.64 (2.90)

*( ) indicates values for port turn
** values are non-dimensionalized by Lpp

Table 5-4: M.V. "Algowest" Turning Circle Manoeuvre Results - Ballast Condition

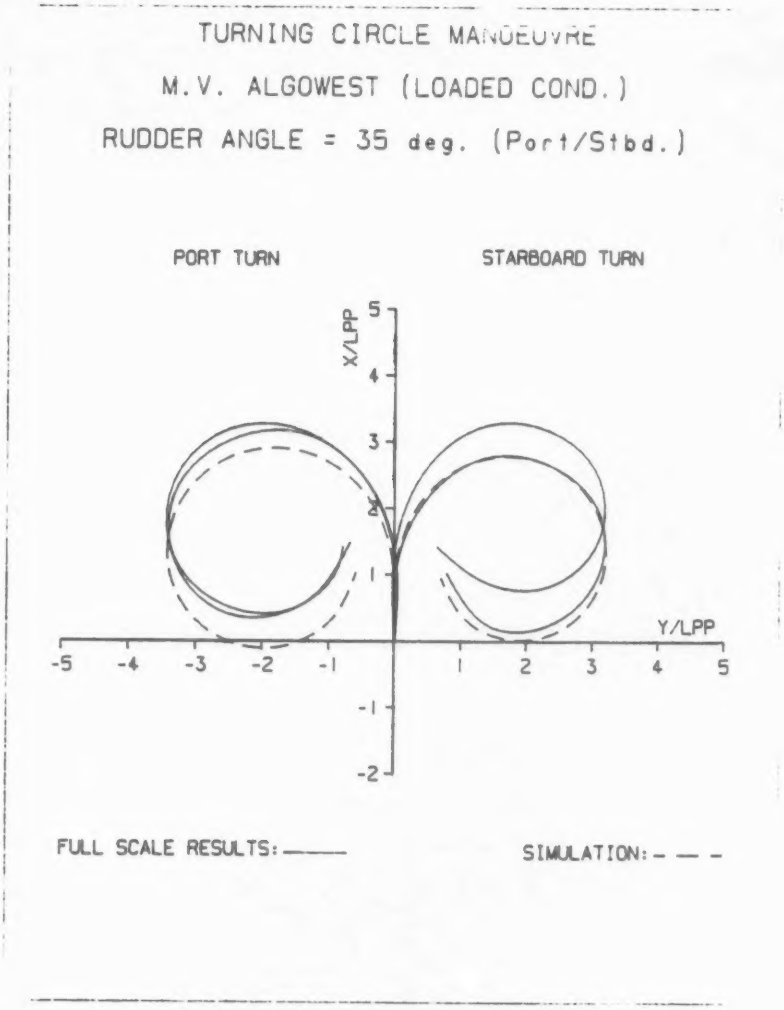


Figure 5-2: M.V. "Algowest" Track During Turning Circle Manoeuvre (Loaded Condition)

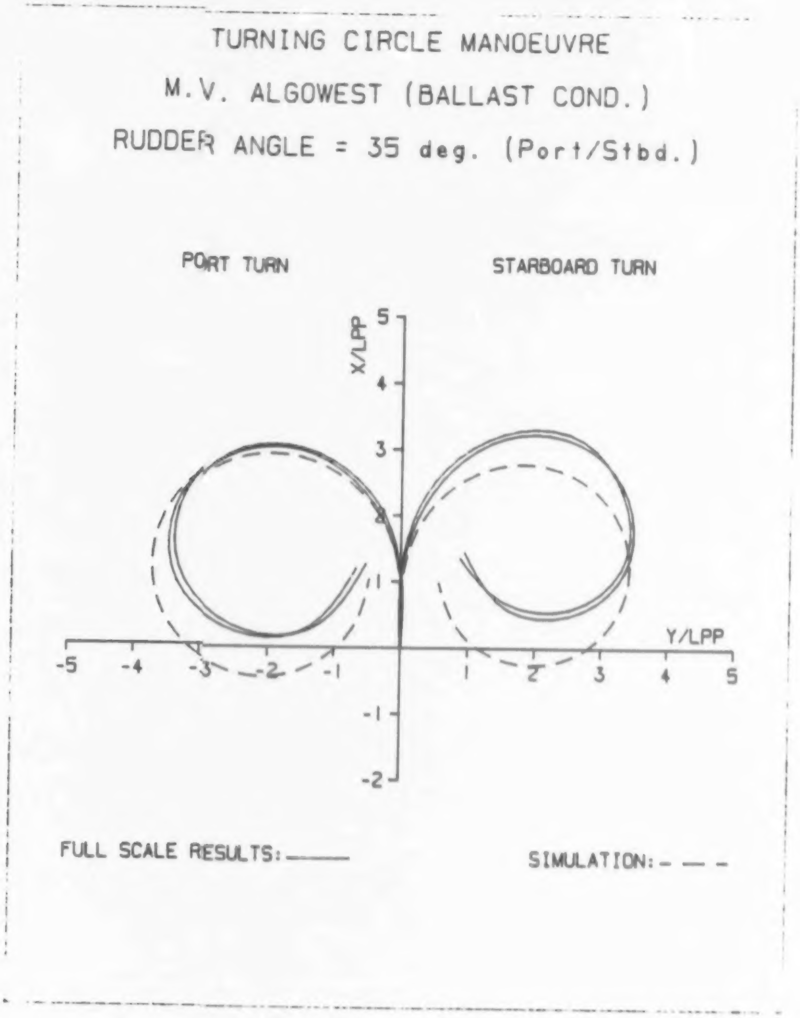


Figure 5-3: M.V. "Algowest's" Track During Turning Circle Manoeuvre (Ballast Condition)

Figure 5-4 (a)

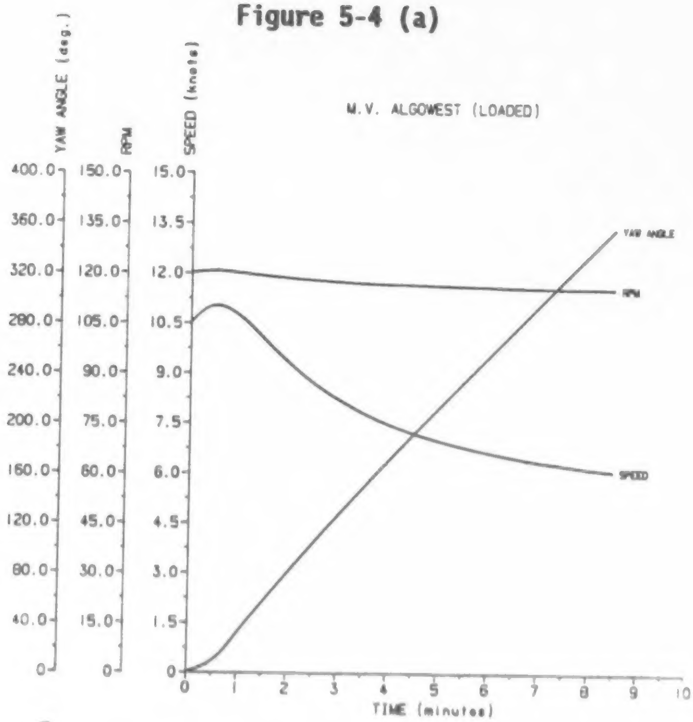


Figure 5-4 (b)

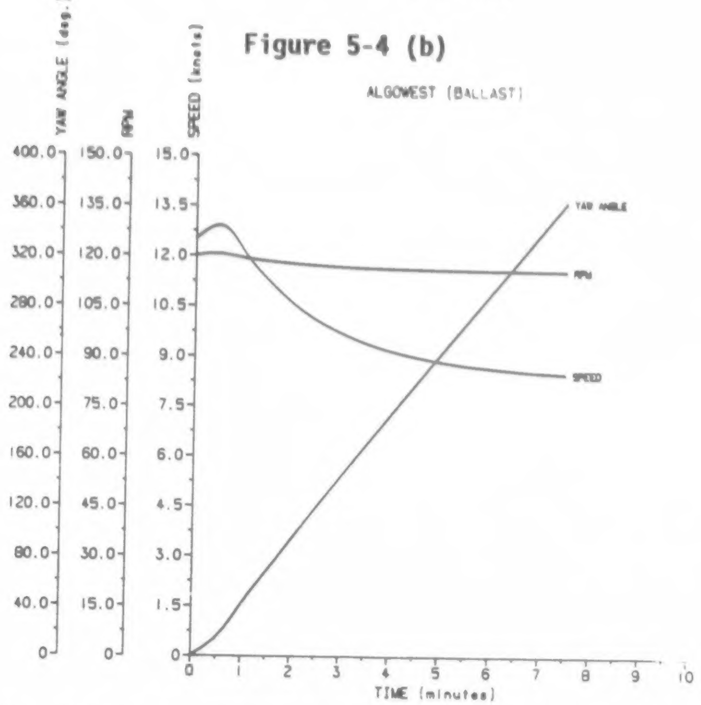


Figure 5-4: M.V. "Algowest" ship Speed, RPM, and Heading During Turning Circle Simulation

path was not obtained because the ship's track could not be recorded.

Tables 5-5 to 5-8 summarize the results of the zigzag manoeuvres (simulated and full scale) for the M.V. "Algowest" in both operating conditions. Figure 5-5 illustrates the yaw angle as a function of time for $20^{0}/20^{0}$ zigzag in ballast condition, and figure 5-6 presents the corresponding plot of the distance travelled normal to the ship's original path (ie., the overshoot width of path). Figures 5-7 and 5-8 present similar information for the $10^{0}/10^{0}$ zigzag in ballast condition and figures 5-9 to 5-12 display the results for the loaded condition. Output from the mathematical simulation is contained in Appendix D.

5.3.4 M.V. "Algowest" Spiral Results

Spiral manoeuvres were conducted on the M.V. "Algowest" in ballast and fully loaded conditions. The manoeuvres were executed starting with a 10^{0} applied rudder angle, as opposed to the simulations which were initiated with a 15^{0} rudder angle. The full scale trials were started at 10^{0} in an effort to save time and also because the critical behaviour of a vessel during a spiral manoeuvre occurs as the rudder angle approaches zero.

Tables 5-9 and 5-10 summarize the results of the simulated and full scale spiral manoeuvres for the M.V. "Algowest" in ballast and fully loaded conditions. The output from the computer simulation is contained in Appendix D. Figures 5-13 and 5-14 illustrate the spiral manoeuvre results and show that the M.V. "Algowest" is dynamically unstable when operating in the fully loaded condition.

Parameter Description	Time Simulation	Full Scale Results	
		Trial 1	Trial 2
Overshoot Angle (degrees)	7.23	5.0	4.5
Non-dimensional* Overshoot Width of Path	0.79	0.68	--
Non-dimensional Reach	3.49	4.24	--
Period between 1st and 3rd Rudder Change (seconds)	189	269.0	276.2

* Values are non-dimensionalized by Lpp

Table 5-5: **M.V. "Algowest"** 20°/20° Zigzag **Manoeuvre** - Ballast Condition

Parameter Description	Time Simulation	Full Scale Results	
		Trial 1	Trial 2
Overshoot Angle (degrees)	3.39	2.0	2.5
Non-dimensional* Overshoot Width of Path	0.36	--	--
Non-dimensional Reach	3.22	--	--
Period between 1st and 3rd Rudder Change (seconds)	154	255	271

* Values are non-dimensionalized by Lpp

Table 5-6: **M.V. "Algowest"** 10°/10° Zigzag **Manoeuvre** - Ballast Condition

Parameter Description	Time Simulation	Full Scale Results
Overshoot Angle (degrees)	12.01	8.0
Non-dimensional *Overshoot Width of Path	1.30	1.13
Non-dimensional Reach	4.30	5.16
Period between 1st and 3rd Rudder Change (seconds)	270	374

* Values are non-dimensionalized by Lpp

Table 5-7: M.V. "Algowest" 20°/20° Zigzag Manoeuvre - Loaded Condition

Parameter Description	Time Simulation	Full Scale Results
Overshoot Angle (degrees)	6.94	7.0
Non-dimensional *Overshoot Width of Path	0.73	0.0
Non-dimensional Reach	4.44	6.17
Period between 1st and 3rd Rudder Change (seconds)	257	371

* Values are non-dimensionalized by Lpp

Table 5-8: M.V. "Algowest" 10°/10° Zigzag Manoeuvre - Loaded Condition

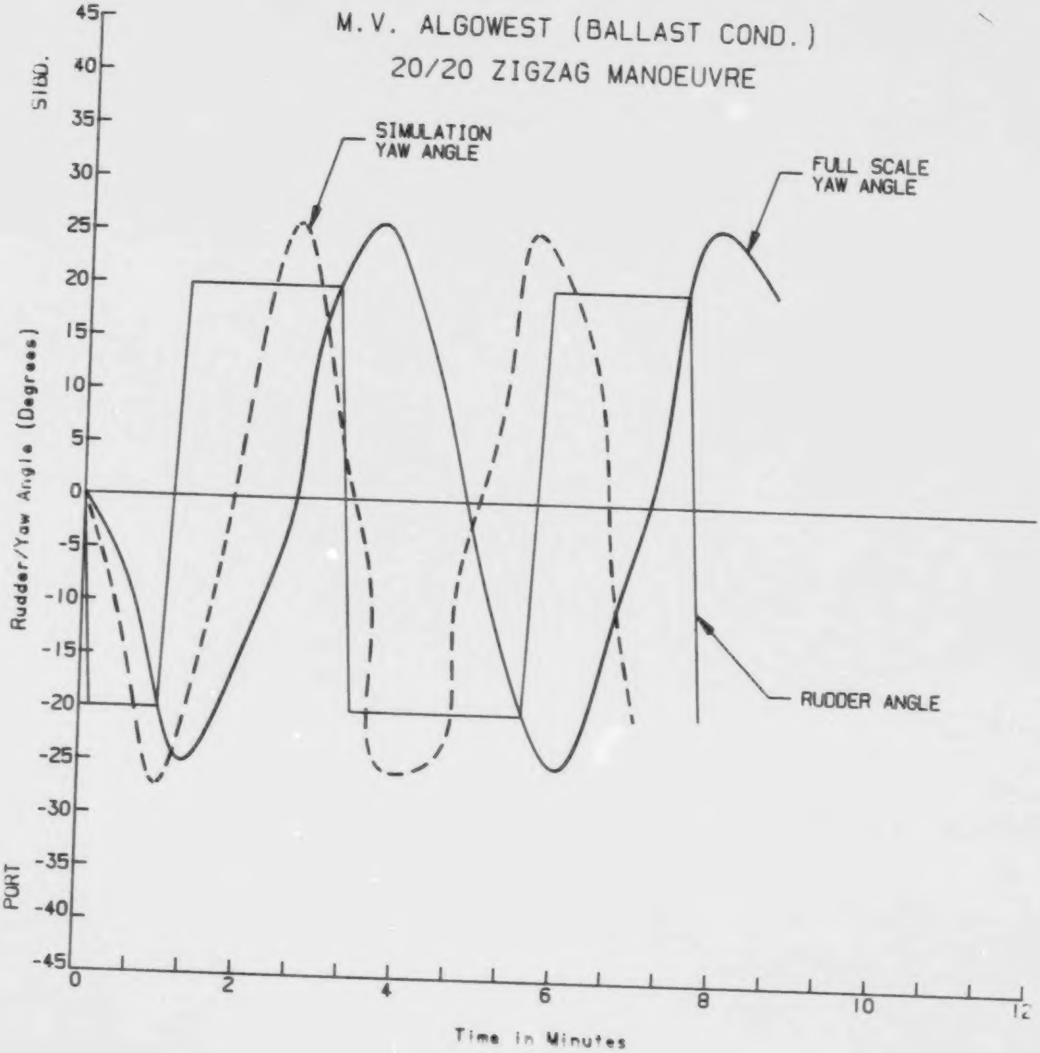


Figure 5-5: M.V. "Algowest" Yaw Angle during 20°/20° Zigzag Manoeuvre (Ballast Condition)

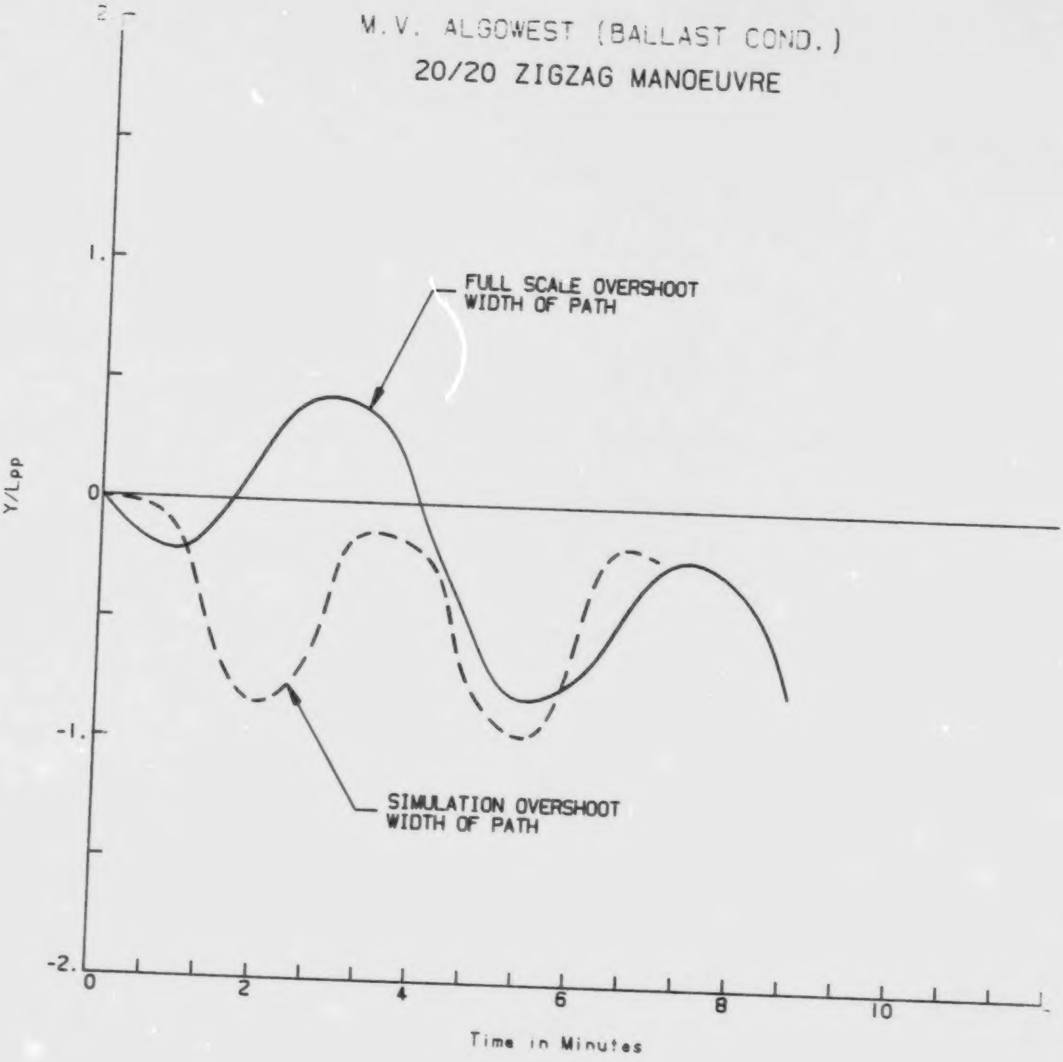


Figure 5-6: M.V. "Algowest" Distance Normal to Ship's Path during $20^0/20^0$ Zigzag Manoeuvre (Ballast Condition)

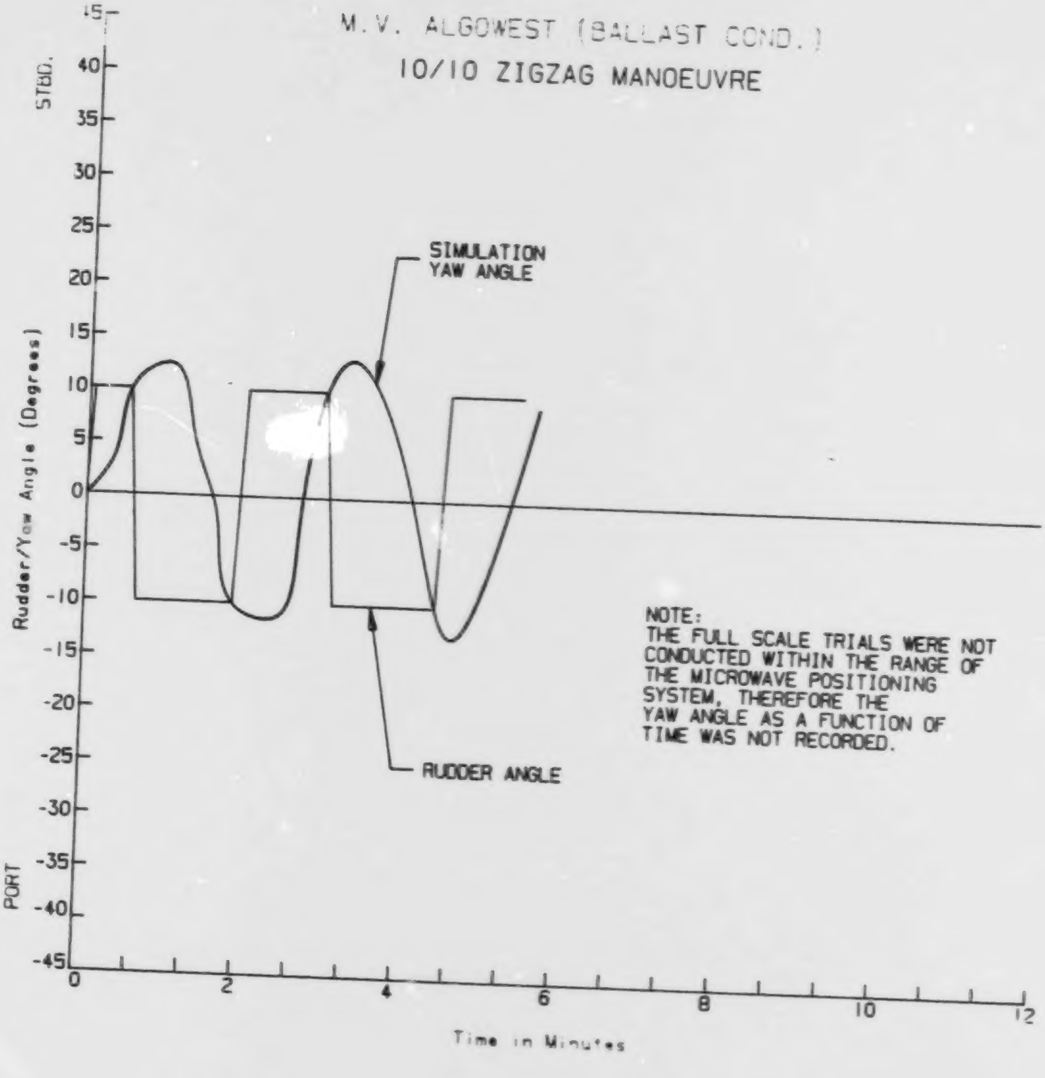


Figure 5-7: M.V. "Algowest" Yaw Angle during $10^o/10^o$ Zigzag Manoeuvre (Ballast Condition)

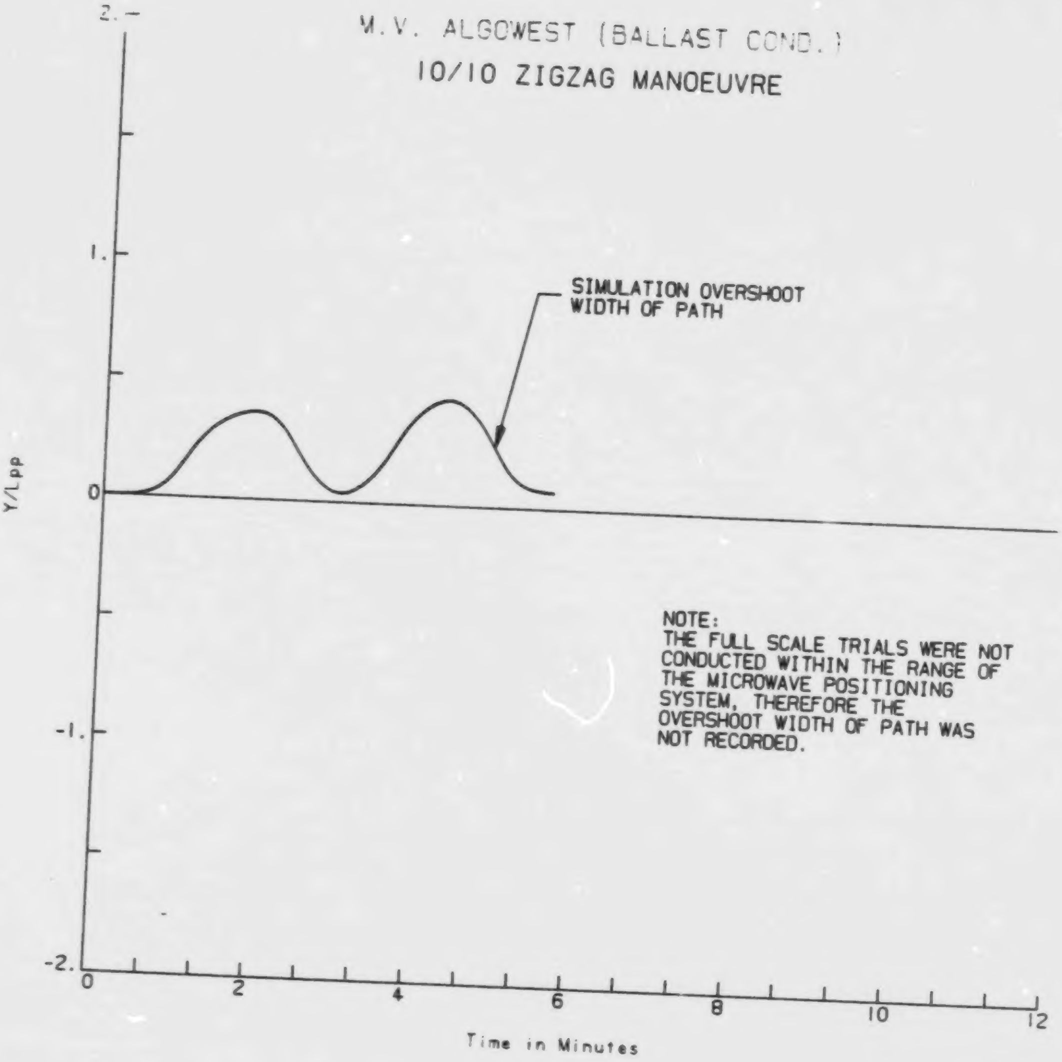


Figure 5-8: M.V. "Algowest" Distance Normal to Ship's Path during $10^o/10^o$ Zigzag Manoeuvre (Ballast Condition)

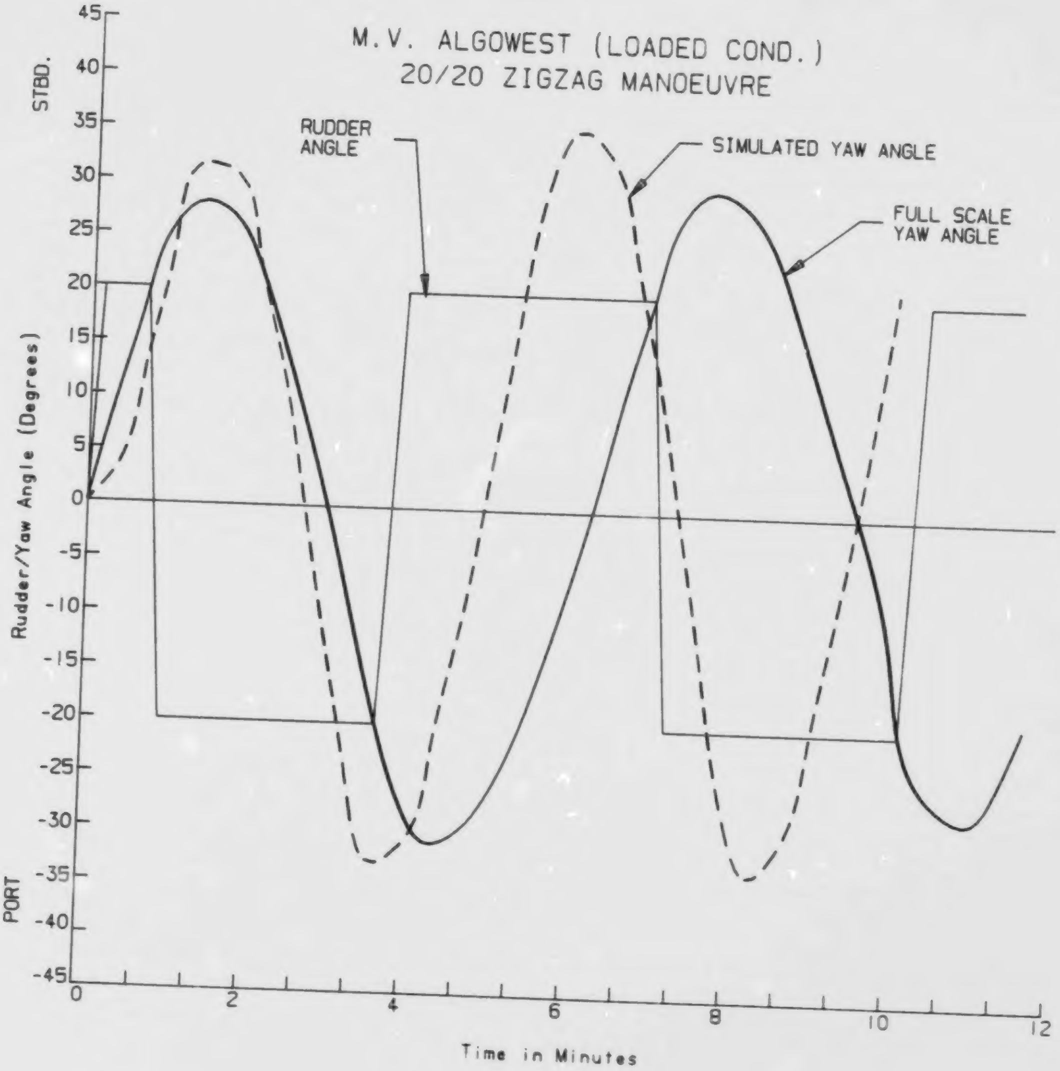


Figure 5-9: M.V. "Algowest" Yaw Angle during $20^0/20^0$ Zigzag Manoeuvre (Loaded Condition)

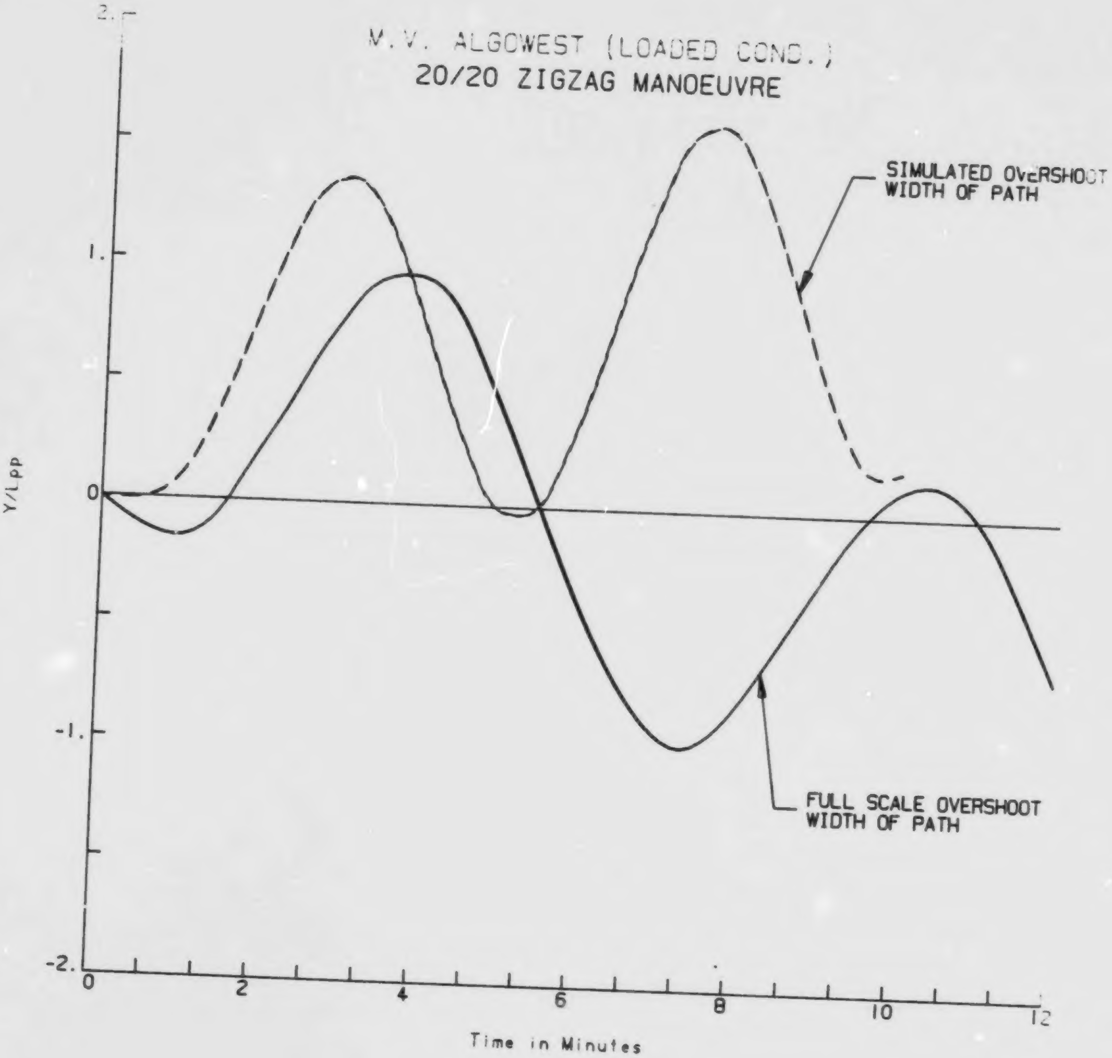


Figure 5-10: M.V. "Algowest" Distance Normal to Ship's Path during $20^0/20^0$ Zigzag Manoeuvre (Loaded Condition)

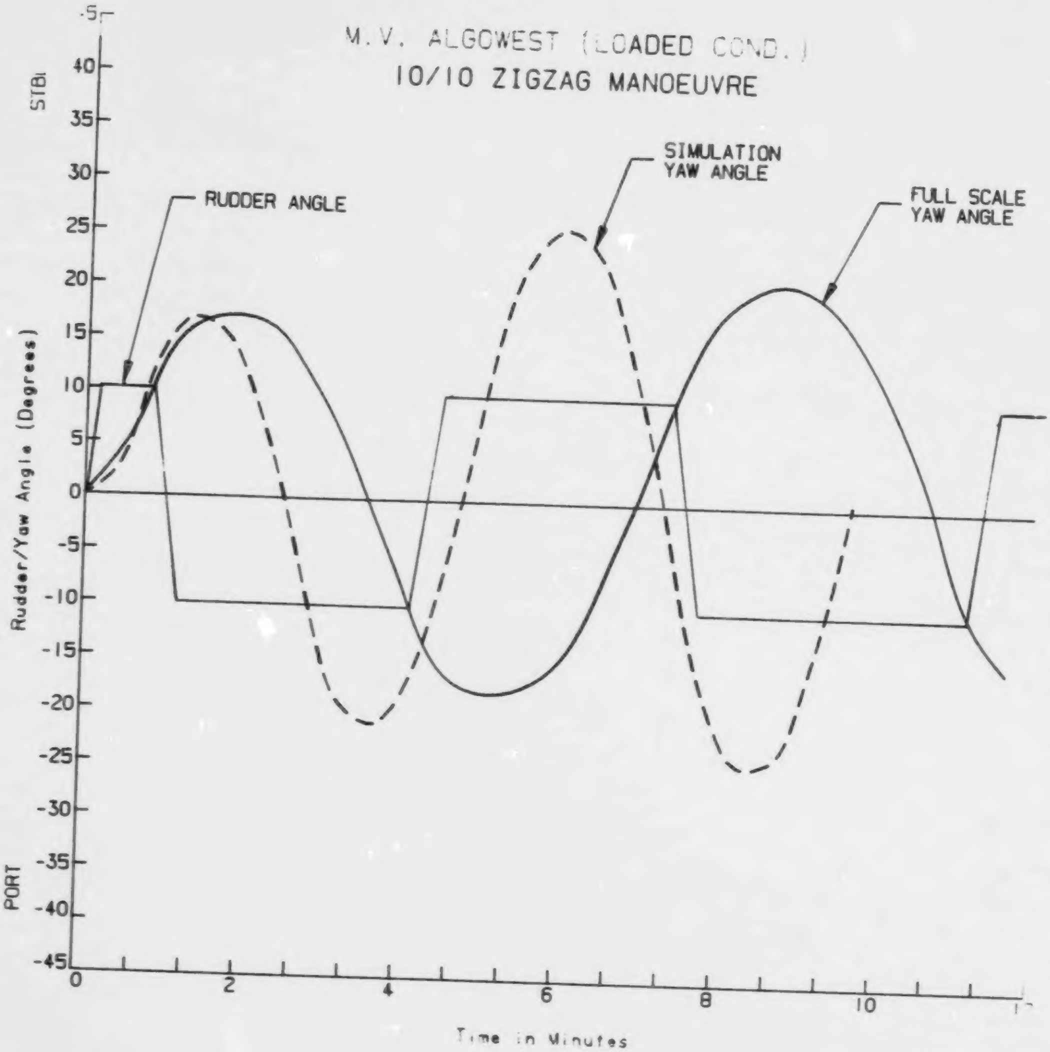


Figure 5-11: M.V. "Algowest" Yaw Angle during 10°/10° Zigzag Manoeuvre (Loaded Condition)

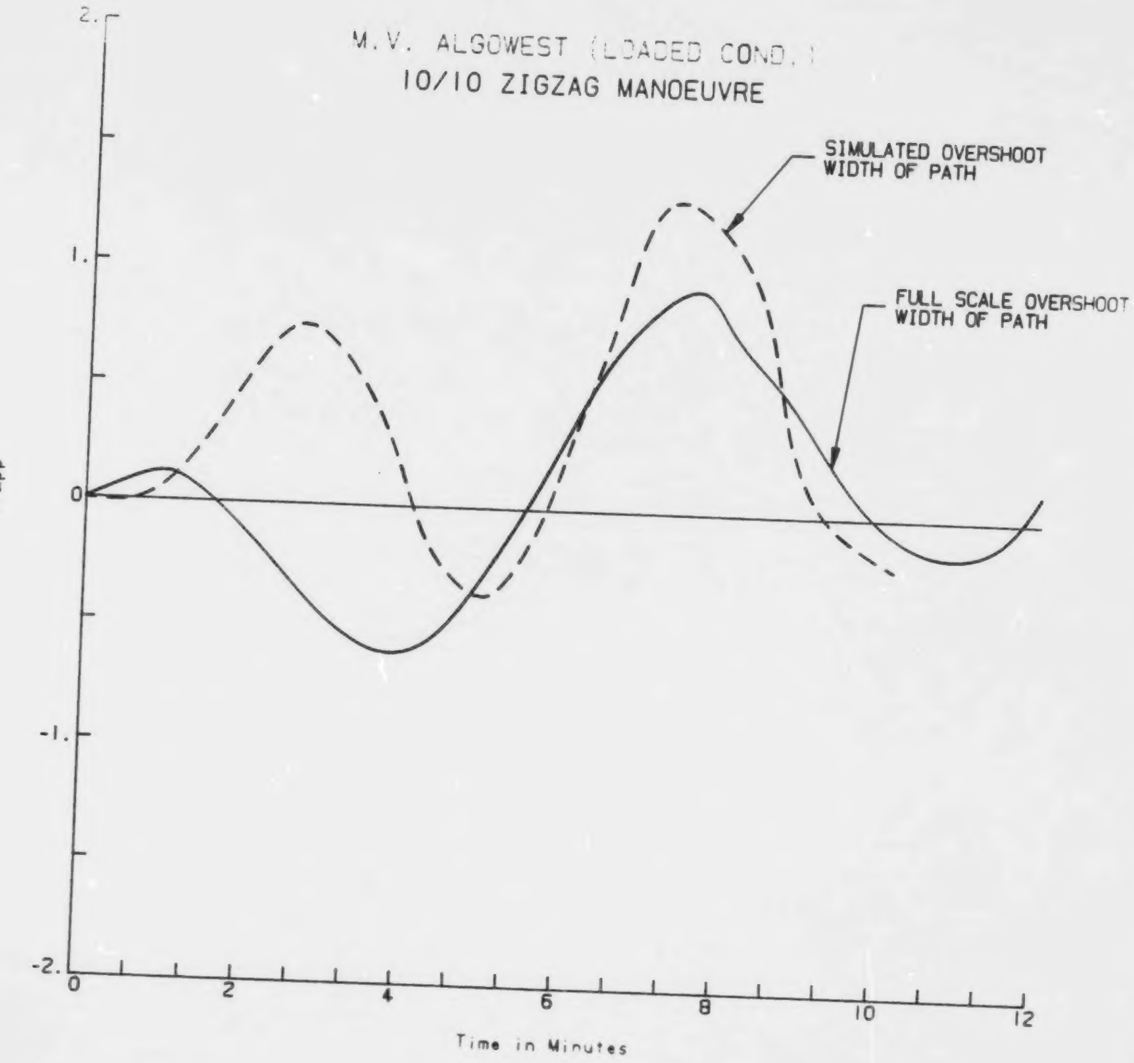


Figure 5-12: M.V. "Algowest" Distance Normal to Ship's Path during $10^0/10^0$ Zigzag Manoeuvre (Loaded Condition)

Applied Rudder Angle (Degrees)	Simulated Yaw Rate (Deg./Sec.)	Full Scale Yaw Rate (Deg./Sec.)
-15	-0.572	--
-10	-0.452	-0.250
- 5	-0.280	-0.130
- 2	--	-0.050
0	0.0	0.0
2	--	0.030
5	0.299	0.140
10	0.485	0.330
15	0.615	--
10	0.478	0.330
5	0.297	0.170
2	--	0.010
0	0.0	0.0
- 2	--	-0.060
- 5	-0.283	-0.110
-10	-0.462	-0.260
-15	-0.588	--

Table 5-9: M.V. "Algowest" Spiral Manoeuvre Results - Ballast Condition

Applied Rudder Angle (Degrees)	Simulated Yaw Rate (Deg./Sec.)	Full Scale Yaw Rate (Deg./Sec.)
-15	-0.652	--
-10	-0.580	-0.390
- 5	-0.489	-0.280
- 2	--	-0.190
0	-0.321	-0.090
2	--	0.230
5	0.570	0.310
10	0.663	0.400
15	0.711	--
10	0.609	0.400
5	0.503	0.280
2	--	0.190
0	0.323	0.190
- 2	--	0.140
- 5	-0.564	-0.280
-10	-0.653	-0.370
-15	-0.699	--

Table 5-10: M.V. "Algowest" Spiral Manoeuvre Results - Loaded Condition

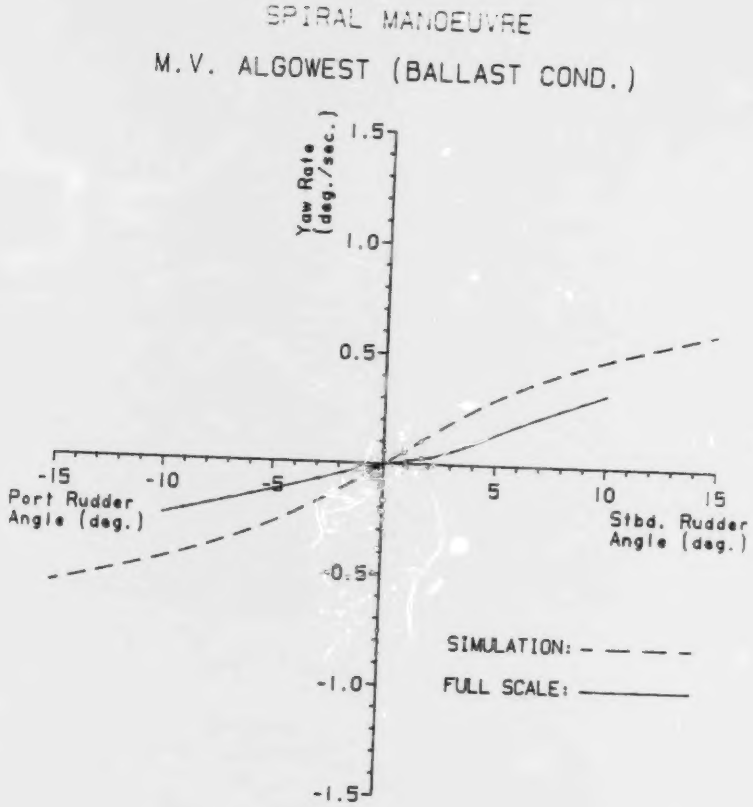


Figure 5-13: Constant Yaw Rate versus Rudder Angle for the M.V. "Algowest" Spiral Manoeuvre (Ballast Condition)

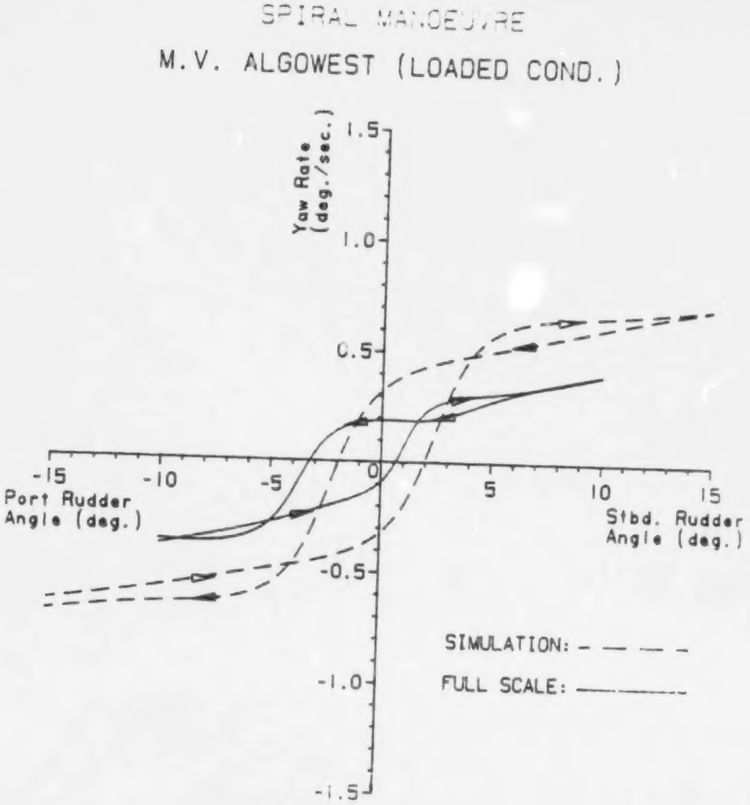


Figure 5-14: Constant Yaw Rate versus Rudder Angle for the M.V. "Algowest" Spiral Manoeuvre (Loaded Condition)

5.3.5 M.V. "Algowest""" Crash Stop Results

An empirical estimate of the M.V. "Algowest's" head reach during a crash stop manoeuvre was obtained using the formula described in section 5.2 of this report. The initial speed of the vessel for both the loaded and ballast conditions was 12 knots. Table 5-11 summarizes the empirical estimates, and the full scale data.

PARAMETER	EMPIRICAL ESTIMATE	FULL SCALE RESULTS	
		TRIAL 1	TRIAL 2
Non-dimensional *Head Reach (Ballast Condition)	4.36	4.92	5.21
Non-dimensional Head Reach (Loaded Condition)	6.79	4.52	6.31

* Non-dimensionalized by Lpp

Table 5-11: M.V. "Algowest" Crash Stop Results

5.3.6 Application to M.V. "Atlantic Freighter"

Ferries comprise a major portion of the Canadian merchant fleet, and were therefore included in this study. The basic ship parameters of the specific vessel (M.V. "Atlantic Freighter") identified for this project are listed in Table 5-12. In addition to representing a different vessel type, this ship was fitted with twin propellers and twin rudders which provided the opportunity to test the applicability of the software to vessels which were not single screw/single rudder.

Parameter Description	Value
Length between perpendiculars	137.0 m
Breadth	19.9 m
Mean Draft	5.25 m
Depth	9.4 m
Mass	9246.0 t
Block Coefficient	0.64
Midship Section Coefficient	0.88
Waterplane Coefficient	0.85
Shaft Horsepower	9888.0 kW
Rudder Area	11.4 m^2
Rudder Aspect Ratio	1.55
Propeller Diameter	4.05 m
Propeller Pitch/Diameter Ratio	1.0
Expanded Blade Area Ratio	[0.8]*

*[ ] indicates an estimated value

Table 5-12: Basic Ferry Parameters

The complete data file, required to run the computer program, is given in Appendix "D" in addition to a hardcopy of the results.

5.3.7 M.V. "Atlantic Freighter" Turning Circle Results

Turning circle manoeuvres were conducted on the M.V. "Atlantic Freighter" using a rudder angle of 35 degrees to port and starboard. The computer simulations were also performed to correspond to the full scale trials. A complete set of simulation results is contained in Appendix D, and Table 5-13 summarizes the full scale, time simulation, and empirical results.

Figures 5-15 and 5-16 illustrate the results generated during the time domain simulation and the full scale trials. It was observed that the RPM remained constant during the full scale manoeuvres, however, it was not recorded on a continuous basis.

PARAMETER DESCRIPTION	TIME SIMULATION	EMPIRICAL ESTIMATE	FULL SCALE RESULTS	
			TRIAL 1	TRIAL 2
Steady Turning Speed (knots)	8.03 (8.30)*	12.19(12.19)	10.8 (9.5)	9.6 (9.8)
Non-dimensional ** Advance	2.94 (2.99)	2.91 (2.91)	3.50 (3.64)	3.39 (3.61)
Non-dimensional Transfer	1.24 (1.28)	1.51 (1.51)	1.75 (1.8)	1.72 (1.74)
Non-dimensional Tactical Diameter	2.96 (3.03)	3.52 (3.52)	3.82 (3.86)	3.77 (4.02)
Non-dimensional Steady Turning Diameter	2.53 (2.65)	3.38 (3.38)	3.58 (3.41)	3.39 (3.51)

*( ) indicates values for port turn
** values are non-dimensionalized by Lpp

Table 5-13: M.V. "Atlantic Freighter" Turning Circle Manoeuvre Results

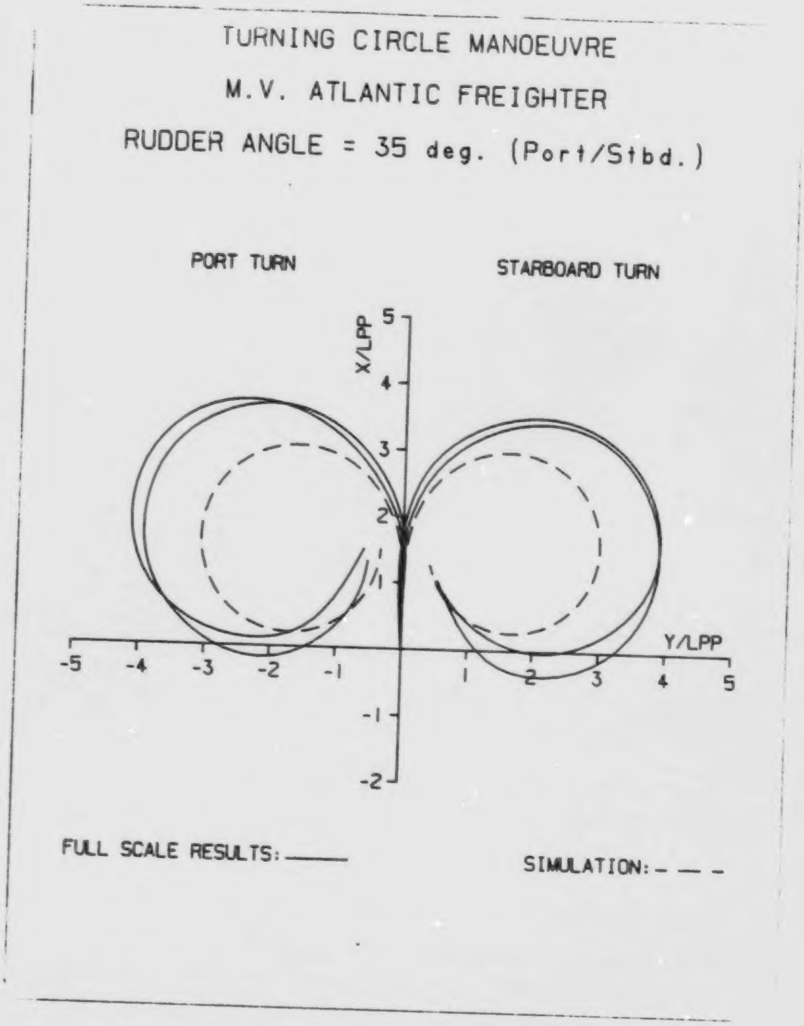


Figure 5-15 : M.V. "Atlantic Freighter" Track During Turning Circle Manoeuvre

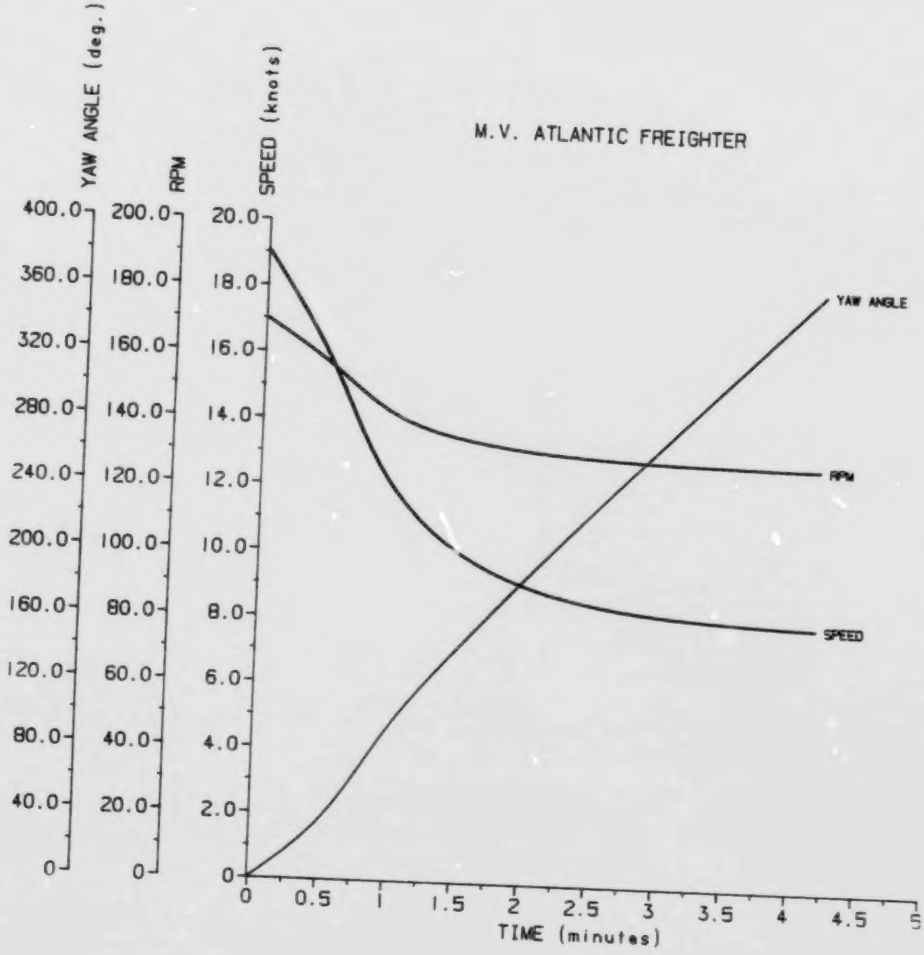


Figure 5-16: M.V. "Atlantic Freighter" Ship Speed, RPM, and Heading During Turning Circle Simulation

5.3.8 M.V. "Atlantic Freighter" Zigzag Results

During the full scale testing of the M.V. "Atlantic Freighter" 10°/10° and 20°/20° zigzag manoeuvres were performed. Computer simulations of both manoeuvres were also executed to determine the ability of the math model to predict the vessel's response during zigzag manoeuvres. The complete set of results from the computer simulations is included in Appendix D, and Tables 5-14 and 5-15 summarize the key parameters obtained from the full scale trials and computer estimates.

Figure 5-17 presents the yaw angle as a function of time for the 20°/20° zigzag manoeuvre and figure 5-18 illustrates the corresponding distance travelled normal to the ship's original path during the manoeuvre. Similarly, figures 5-19 and 5-20 summarize the 10°/10° zigzag manoeuvre.

5.3.9 M.V. "Atlantic Freighter" Spiral Results

For the M.V. "Atlantic Freighter", spiral manoeuvres were conducted with an initial rudder angle of 15° to starboard, and also 15° to port. Corresponding computer simulations were also performed, the results of which can be found in Appendix D. Tables 5-16 and 5-17 summarize the constant yaw rates as recorded during the trials and predicted by the computer model, for each of the spirals. However, only the spiral manoeuvre with an initial angle of 15° to starboard has been plotted in figure 5-21, because the results using an initial rudder angle to port are very similar.

Parameter Description	Time Simulation	Full Scale Results
Overshoot Angle (degrees)	22.23	12.0
Non-dimensional *Overshoot Width of Path	1.88	1.75
Non-dimensional Reach	4.93	4.25
Period between 1st and 3rd Rudder Change (seconds)	149.0	130.0

* Values are non-dimensionalized by Lpp

Table 5-14: M.V. "Atlantic Freighter" 20°/20° Zigzag Manoeuvre

Parameter Description	Time Simulation	Full Scale Results
Overshoot Angle (degrees)	9.78	8.0
Non-dimensional *Overshoot Width of Path	0.86	1.18
Non-dimensional Reach	4.78	5.12
Period between 1st and 3rd Rudder Change (seconds)	123.0	107.8

* Values are non-dimensionalized by Lpp

Table 5-15: M.V. "Atlantic Freighter" 10°/10° Zigzag Manoeuvre

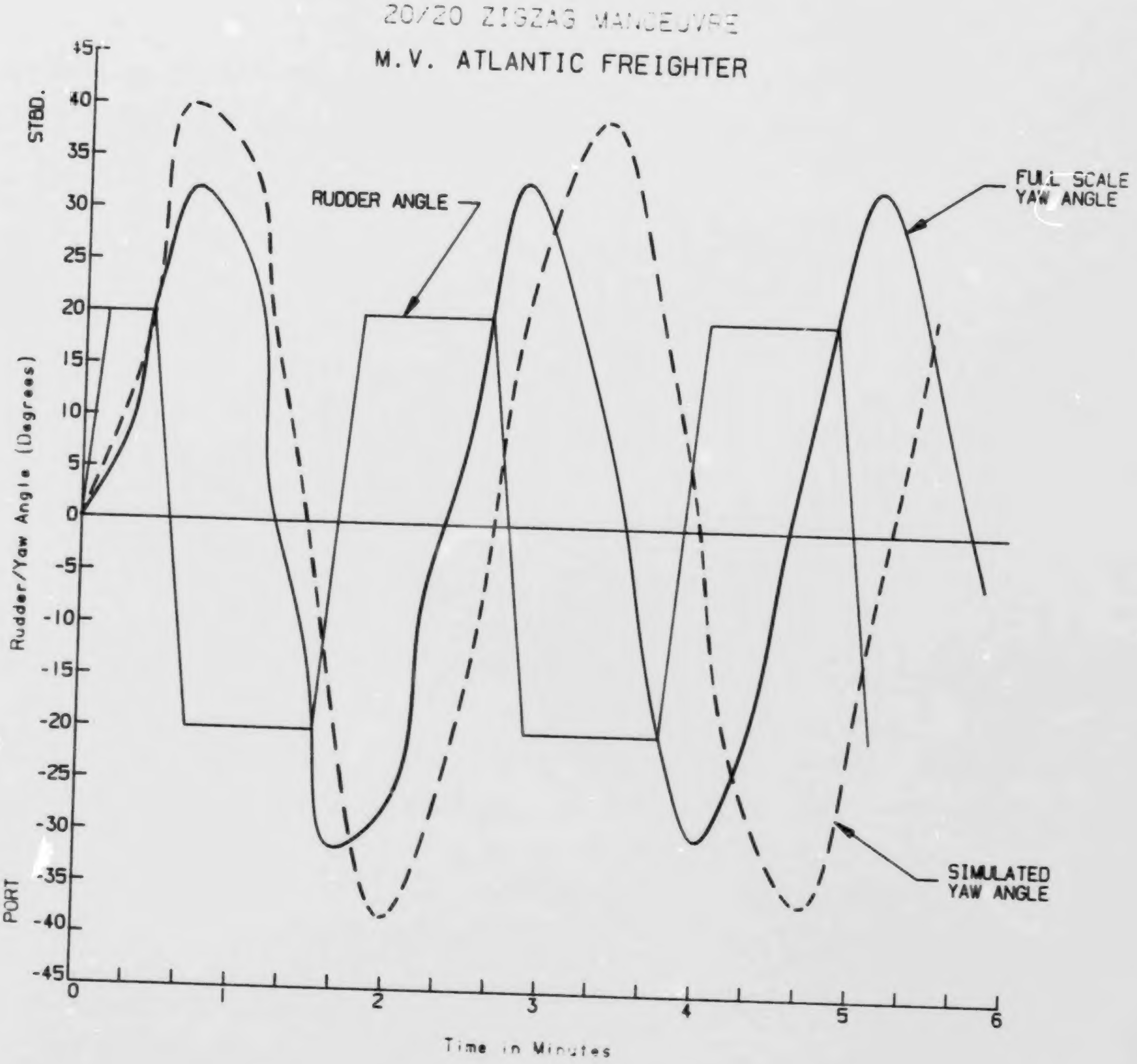


Figure 5-17: M.V. "Atlantic Freighter" Yaw Angle during 20°/20° Zigzag Manoeuvre

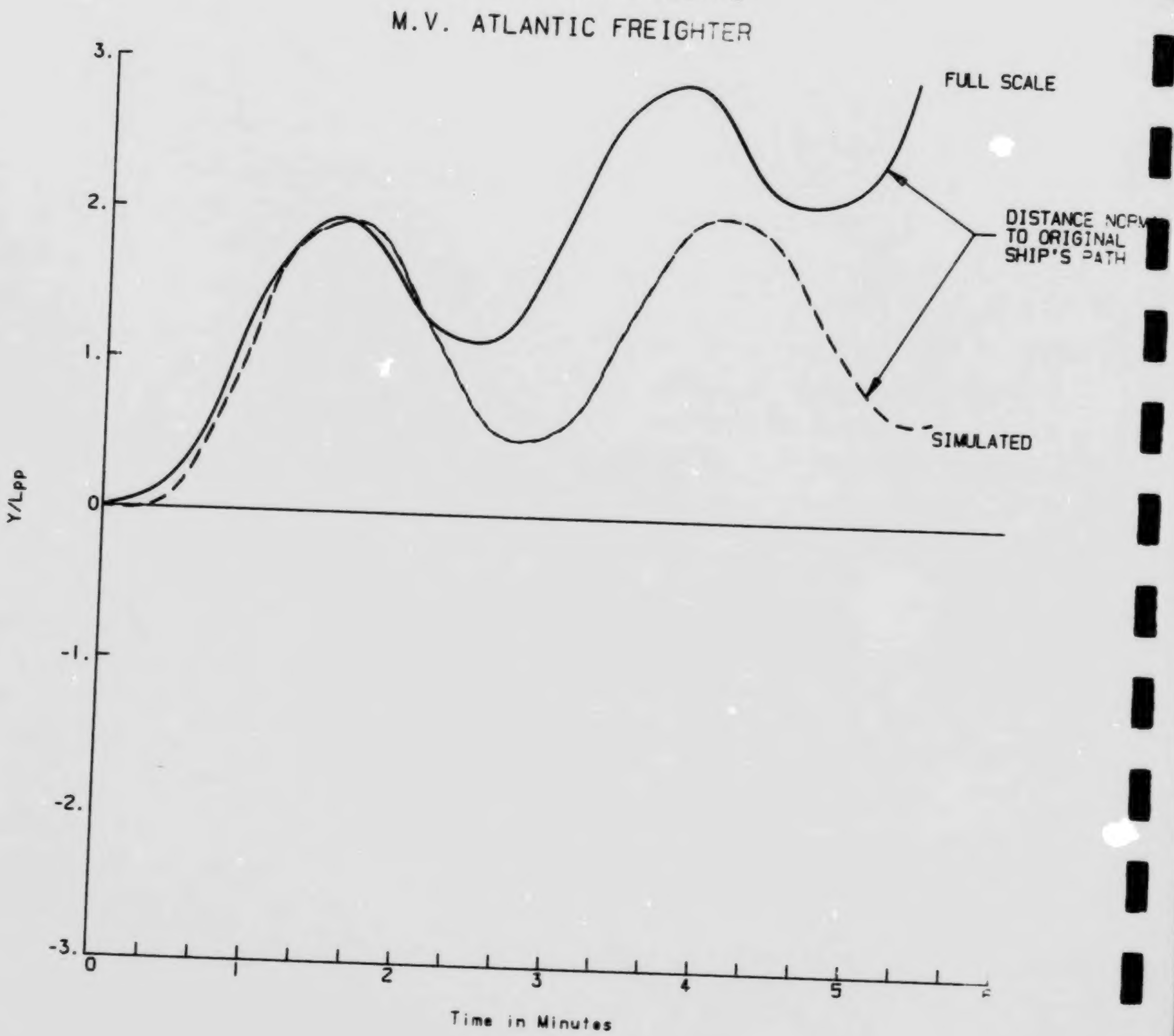


Figure 5-18: M.V. "Atlantic Freighter" Distance Normal to Ship's Path during 20°/20° Zigzag Manoeuvre

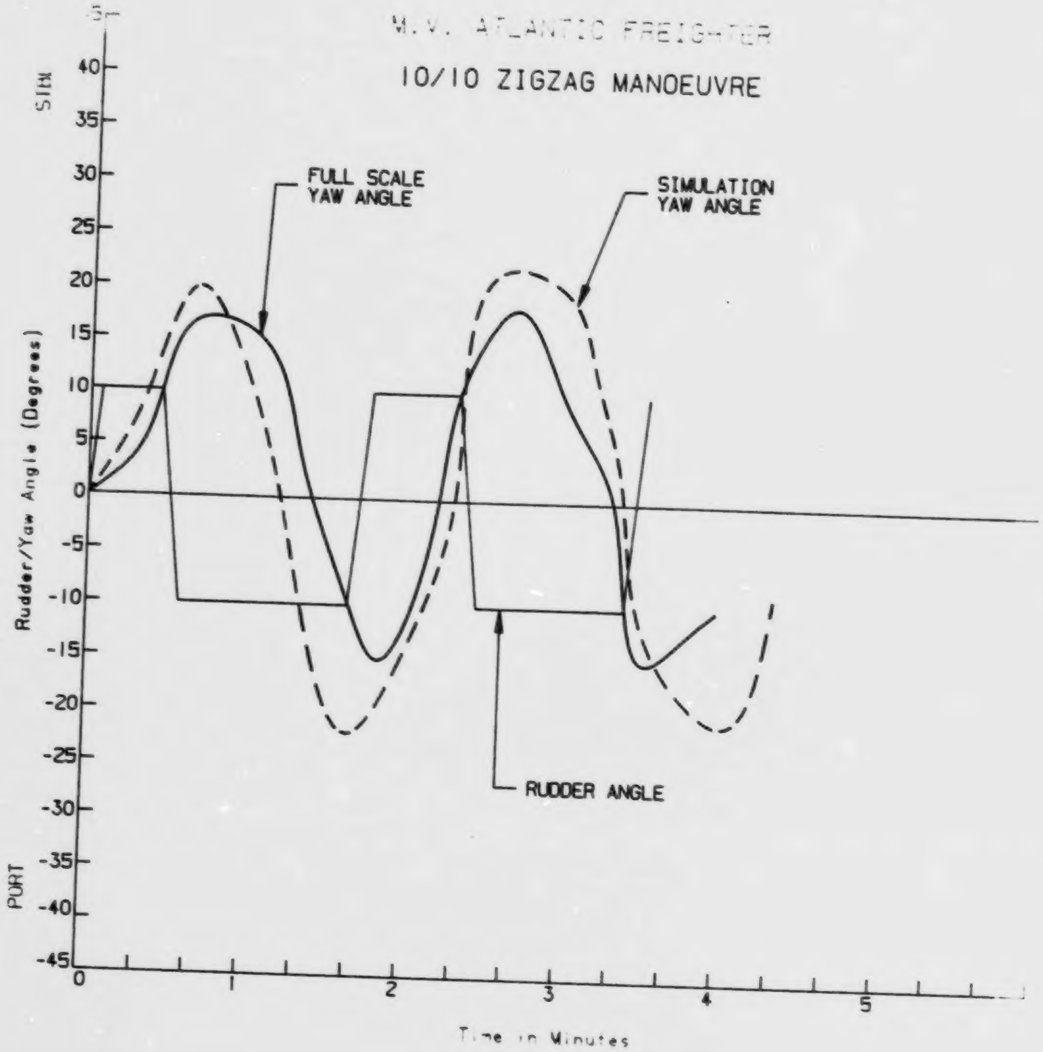


Figure 5-19: M.V. "Atlantic Freighter" Yaw Angle during 10°/10° Zigzag Manoeuvre

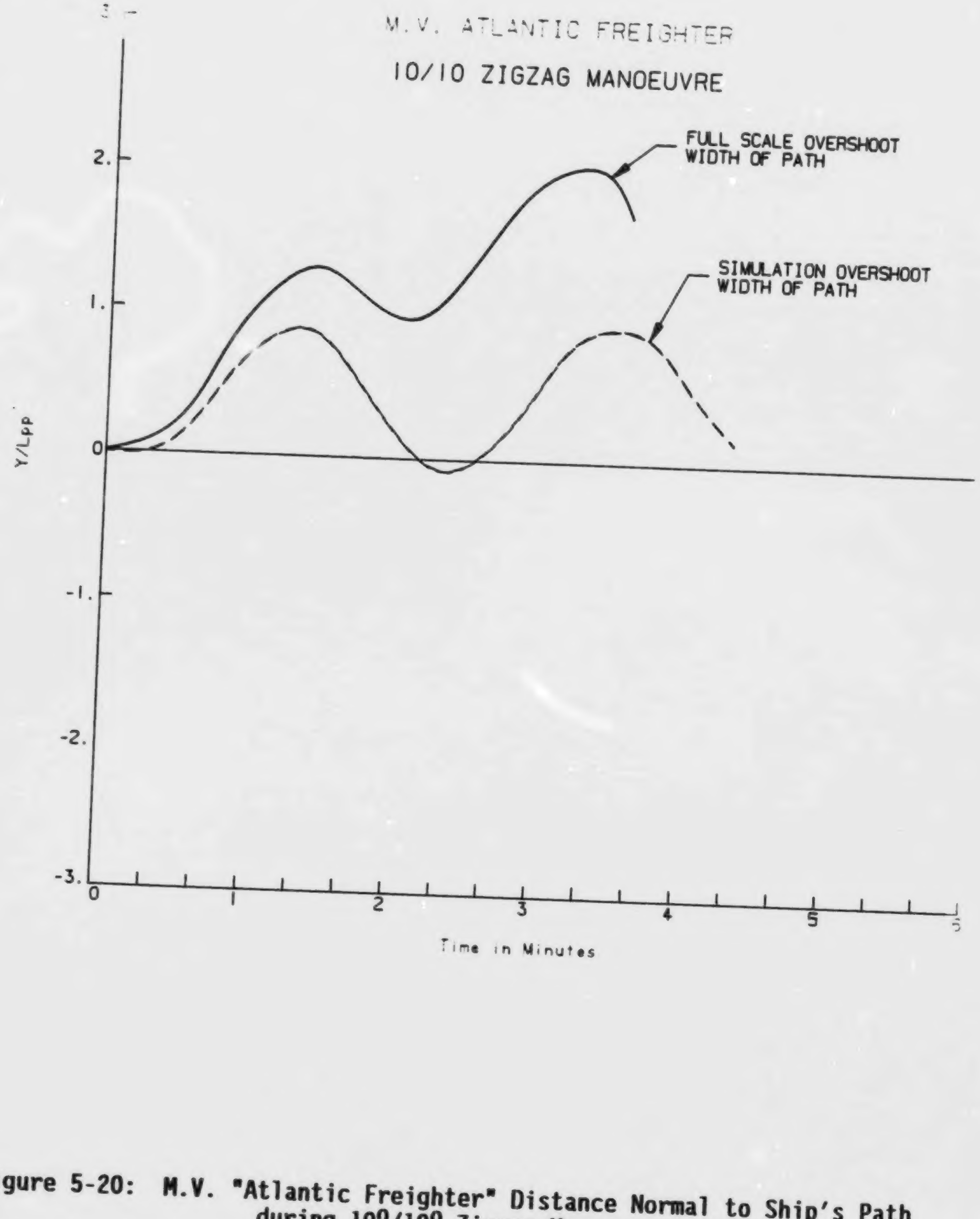


Figure 5-20: M.V. "Atlantic Freighter" Distance Normal to Ship's Path during $10^0/10^0$ Zigzag Manoeuvre

Applied Rudder Angle (Degrees)	Simulated Yaw Rate (Deg./Sec.)	Full Scale Yaw Rate (Deg./Sec.)
-15	-1.25	-1.0
-10	-1.06	-0.79
- 5	-0.82	-0.36
- 2	--	-0.16
0	-0.16	0.15
2	--	0.31
5	0.88	0.48
10	1.11	0.84
15	1.23	1.03
10	1.06	0.76
5	0.83	0.46
2	--	0.24
0	0.16	0.03
- 2	--	-0.14
- 5	-0.87	-0.47
-10	-1.09	-0.79
-15	-1.21	-1.0

Table 5-16: M.V. "Atlantic Freighter" Spiral Manoeuvre Results - (initial angle 15° port)

Applied Rudder Angle (Degrees)	Simulated Yaw Rate (Deg./Sec.)	Full Scale Yaw Rate (Deg./Sec.)
15	-1.27	1.03
10	-1.07	0.82
5	0.83	0.49
2	--	0.30
0	0.16	0.0
- 2	--	-0.17
- 5	-0.87	-0.43
-10	-1.09	-0.77
-15	-1.21	-1.02
-10	-1.05	-0.73
- 5	-0.82	-0.25
- 2	--	-0.03
0	-0.16	0.10
2	--	0.38
5	0.88	0.54
10	1.11	0.81
15	1.23	1.05

Table 5-17: M.V. "Atlantic Freighter" Spiral Manoeuvre Results - (initial angle 15° starboard)

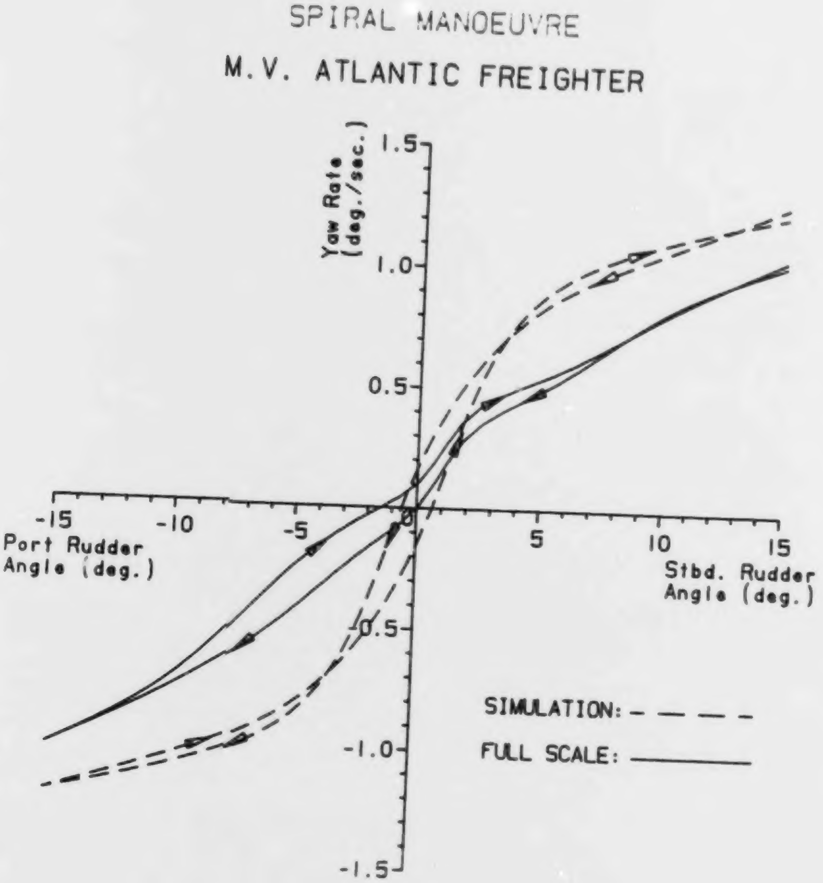


Figure 5-21: M.V. "Atlantic Freighter" Spiral Manoeuvre Results

5.3.10 M.V. "Atlantic Freighter" Crash Stop Results

The empirical relationship presented in section 5.2 of this report was used to predict the head reach of the M.V. "Atlantic Freighter" during a crash stop manoeuvre, from an initial speed of 19 knots. Two full scale trials were also executed. Table 5-18 summarizes the results for the crash stop manoeuvre.

	Non-dimensional* Head Reach
Empirical estimate	4.48
Full scale trial #1	4.74
Full scale trial #2	4.63

* Non-dimensionalized by Lpp

Table 5-18: M.V. "Atlantic Freighter" Crash Stop Results

5.4 DISCUSSION OF RESULTS

The discussion which follows used the results of the full scale trials as the reference position. This was considered reasonable because the trials were conducted in ideal environmental conditions and were, for the majority of the tests, performed within range of a microwave positioning system, which provided precise ship's track data and related information.

A comparison was made between the full scale results, the computer simulation estimates and the empirical estimates. An additional comparison was made using the data contained in the manoeuvring database (ref. 23). The primary purposes of these comparisons were to:

- identify the limitations of the computer model and suggest possible modifications, and

- assess the validity of the information contained in the manoeuvring database.

5.4.1 Comparison of Model/Full Scale Results

5.4.1.1 M.V. "Algowest" Turning Circle Manoeuvre

The results of the turning circle manoeuvre for the M.V. "Algowest", in the loaded and ballast conditions, were presented in Tables 5-3 and 5-4 respectively. Using the average of the two full scale trials which were conducted, Tables 5-19 and 5-20 were prepared. They summarize the percentage difference between the predictions and full scale data.

Parameter	Time Simulation	Empirical Estimate
Steady Turning Speed	+ 23.7 (+34.2)**	-21.0 (-12.8)
Non-dimensional Advance	-10.6 (-11.3)	- 5.3 (+ 2.5)
Non-dimensional Transfer	-16.0 (-15.0)	- 6.0 (+13.1)
Non-dimensional Tactical Diameter	+ 0.6 (+ 0.3)	- 4.5 (+13.2)
Non-dimensional Steady Turning Diameter	- 1.7 (+ 0.4)	- 3.3 (+19.3)

**( ) values in parentheses are for port turns.

Table 5-19: Percentage Difference between Full Scale Results and Predictions - M.V. "Algowest" Turning Circle Manoeuvre Loaded Condition

Parameter	Time Simulation	Empirical Estimate
Steady Turning Speed	+23.2 (+53.7)**	-24.2 (- 1.3)
Non-dimensional Advance	-15.0 (- 4.3)	+ 0.6 (+21.4)
Non-dimensional Transfer	-10.9 (- 1.3)	+12.3 (+41.7)
Non-dimensional Tactical Diameter	- 2.3 (+10.6)	+ 5.5 (+34.1)
Non-dimensional Steady Turning Diameter	+ 2.2 (+ 9.8)	+13.0 (+37.5)

* ( ) values in parentheses are for port turns.

Table 5-20: **Percentage Difference between Full Scale Results and Predictions - M.V. "Algowest" Turning Circle Manoeuvre Ballast Condition**

The computer simulation predictions were within 10% of the tactical and steady turning diameter, and 16% of the advance and transfer. The steady turning speed was overestimated by the computer model.

Empirical estimates were more variable than the simulated results. For starboard turns, the estimates for all parameters except the final speed were within 13% of the full scale data, however, the same characteristics for the port turns were not predicted accurately. The speed predictions were also inconsistent.

Overall, the computer simulation provided the best predictions for the turning circle manoeuvre, apart from the steady turning speed. The empirical estimates were reasonable for the starboard turn, however, they showed a high degree of variability for the port turn.

5.4.1.2 M.V. "Algowest" Zigzag Manoeuvre

The M.V. "Algowest" performed 10°/10° and 20°/20° zigzag manoeuvres, and the results were presented in Tables 5-5 to 5-8. The percentage difference between the actual data and the estimates predicted by the computer simulation are summarized in Table 5-21 for both the ballast and loaded conditions.

Parameter	10°/10°		20°/20°	
	Ballast	Loaded	Ballast	Loaded
Overshoot Angle	+50.7	- 0.9	+52.2	+50.1
Overshoot Width of Path	--	--	+16.2	+15.0
Reach	--	-28.0	-17.7	-16.7
Period	-41.4	-30.7	-30.7	-27.8

Table 5-21: **Percentage Difference between Full Scale Results and Predictions - M.V. "Algowest" 10°/10° and 20°/20° Zigzag Manoeuvre**

With the exception of the predicted overshoot angle during the 10°/10° manoeuvre in the loaded condition, all parameters were either overestimated or underestimated by at least 15%. The computer model did not predict the zigzag manoeuvre characteristics particularly accurately. It should be noted however, that the magnitudes of the full scale overshoot angles were small, therefore the percentages can be misleading. For example, the measured angle for the 10°/10° zigzag in the ballast condition was 2.25°, and the computer model predicted 3.39°.

5.4.1.3 M.V. "Algowest" Spiral Manoeuvre

The full scale spiral manoeuvres were conducted with an initial rudder angle of 10° to port. Table 5-9 and 5-10 summarized the estimated and full scale data for both ship operating conditions. The percentage differences are summarized in Table 5-22.

Angle	Operating Condition	
	Ballast	Loaded
-15	--	--
-10	+ 80.8	+ 48.7
- 5	+115.4	+ 74.6
- 2	--	--
0	0.0	+256.7
2	--	--
5	+113.6	+ 83.9
10	+ 47.0	+ 65.8
15	--	--
10	+ 44.8	+ 52.3
5	+ 74.7	+ 79.6
2	--	--
0	0.0	+ 70.0
- 2	--	--
- 5	+157.3	+101.4
-10	+ 77.7	+ 76.5
-15	--	--

Table 5-22 : Percentage Difference between Full Scale Results and Predictions - M.V. "Algowest" Spiral Manoeuvre

The computer model was unable to accurately predict the constant yaw rate for a particular rudder angle. In all cases, the model overestimated the yaw rates by a minimum of 50%. Notwithstanding the poor predictions of yaw rate, the model did predict the correct trends which the ship exhibited during the full scale trials.

In the ballast condition, the M.V. "Algowest" was dynamically stable, and this behaviour was predicted by the computer model. Similarly, the vessel was dynamically unstable when operated in the loaded condition, which was also predicted by the model.

5.4.1.4 M.V. "Algowest" Crash Stop Manoeuvre

The final manoeuvre which was conducted on the M.V. "Algowest" was the crash stop. The results of the tests were summarized in Table 5-11, and the percentage differences between the full scale results and empirical estimates are presented in Table 5-23.

Parameter	Empirical Estimate
Head Reach - Ballast Condition	-14.0
Head Reach - Loaded Condition	+25.3

Table 5-23 : Percentage Difference between Full Scale Results and Predictions - M.V. "Algowest" Crash Stop Manoeuvre

The empirical estimate was reasonable for the ballast condition, however, it was too conservative for the prediction of head reach in the loaded condition.

5.4.1.5 M.V. "Atlantic Freighter" Turning Circle Manoeuvre

Results of the turning circle manoeuvre simulations and trials were presented in Table 5-13. The percentage differences between the measured data and the predictions were calculated for the M.V. "Atlantic Freighter" and are summarized in Table 5-24.

Parameter	Time Simulation	Empirical Estimate
Steady Turning Speed	-21.3 (-14.0)**	+19.5 (+26.32)
Non-dimensional Advance	-14.8 (-17.5)	-15.7 (-19.7)
Non-dimensional Transfer	-28.5 (-27.7)	-13.0 (-14.7)
Non-dimensional Tactical Diameter	-22.1 (-22.1)	- 7.4 (- 9.5)
Non-dimensional Steady Turning Diameter	-27.5 (-23.4)	- 3.2 (- 2.3)
**( ) values in parentheses are for port turns.		

Table 5-24 : Percentage Difference between Full Scale Results and Predictions - M.V. "Atlantic Freighter" Turning Circle Manoeuvre

The computer simulation consistently underestimated the parameters of the manoeuvre by 15% to 29%, a somewhat worse performance then with the "Algowest". Based upon these results, one may conclude that the modifications made to the original algorithm of reference 1 (refer to section 4.1 of this report), to accommodate twin screw/twin rudder ships, were insufficient to account fully for the effects present.

The empirical estimates of the tactical and steady turning diameters were within 10% of the full scale data, however, the remaining parameters were not predicted with the same degree of accuracy.

5.4.1.6 M.V. "Atlantic Freighter" Zigzag Manoeuvre

A $10^o/10^o$ and a $20^o/20^o$ zigzag manoeuvre was performed during the full scale testing of the M.V. "Atlantic Freighter". These manoeuvres were executed within the range of the microwave positioning system and a summary of the results was given in Tables 5-14 and 5-15. The differences between the predicted values obtained from the computer simulations and the trials are presented in the table below.

Parameter	$10^o/10^o$	$20^o/20^o$
Overshoot Angle	+22.3	+85.3
Overshoot Width of Path	-27.1	+ 7.4
Reach	- 6.6	+16.0
Period	+14.1	+14.6

Table 5-25: Percentage Difference between Full Scale Results and Predictions - M.V. "Atlantic Freighter" $10^o/10^o$ and $20^o/20^o$ Zigzag Manoeuvre

The information contained in Table 5-25 shows that the computer simulation predicted the responses of the M.V. "Atlantic Freighter" during the zigzag manoeuvres with reasonable accuracy again with the exception of the overshoot angle.

5.4.1.7 M.V. "Atlantic Freighter" Spiral Manoeuvre

Two spiral manoeuvres were conducted during the full scale trials. One of the tests started with an initial rudder angle of 15^o to port, and the other with an angle of 15^o to starboard. Results of these tests were given in Tables 5-16 and 5-17. The difference between the simulated yaw rate and the actual measured data is expressed as a percentage in Table 5-26.

Applied Rudder Angle* (Degrees)		% Difference Initial Angle 15° port	% Difference Initial Angle 15° stbd.
-15	(15)	+ 25.0	+ 23.3
-10	(10)	+ 34.2	+ 30.5
- 5	(5)	+127.8	+ 69.4
- 2	(2)	--	--
0	(0)	-206.7	NA**
2	(- 2)	--	--
5	(- 5)	+ 83.3	+102.3
10	(-10)	+ 32.1	+ 41.6
15	(-15)	+ 19.4	+ 18.6
10	(-10)	+ 39.4	+ 43.8
5	(- 5)	+ 80.4	+228.0
2	(- 2)	--	--
0	(0)	+433.3	-260.0
- 2	(2)	--	--
- 5	(5)	+297.9	+ 63.0
-10	(10)	+ 38.0	+ 37.0
-15	(15)	+ 21.0	+ 17.1

* -ve sign indicates port rudder angle

** The % difference was not computed because the measured yaw rate was 0.0 deg/sec. and the predicted yaw rate was 0.16 deg/sec.

Table 5-26: Percentage Difference between Full Scale Results and Predictions - M.V. "Atlantic Freighter" Spiral Manoeuvre

The computer model overestimated the magnitudes of the constant yaw rate for the majority of rudder angles, similar to the predictions for the M.V. "Algowest". The M.V. "Atlantic Freighter", during the spiral manoeuvres, was dynamically unstable. This characteristic was predicted by the computer model.

5.4.1.8 M.V. "Atlantic Freighter" Crash Stop Manoeuvre

During the full scale trials program, two crash stop manoeuvres were conducted. The results of these manoeuvres, along with the empirical estimate, were presented in Table 5-18. The mean value for the non-dimensional head reach, measured during the trials, was 4.69. In terms of percentages, the empirical estimate was 4.4% below the mean.

5.4.2 Sensitivity Analysis

The comparison of results which was presented in the previous section of this report indicated that the computer model required refinements and/or modifications, to accommodate vessels fitted with twin screws/twin rudders, and also to increase the accuracy of predictions for the conventional single screw vessels. In addition, the variability of the computer model results when compared to the full scale data suggested that certain parameters within the model were affecting the final results more significantly than others.

A limited sensitivity analysis was conducted to determine the effects of varying certain key model parameters. The range of variation for the parameters which were tested represented the variability of these parameters that would be expected during the preliminary design phase. The parameters which were studied were the propeller blade area ratio (BAR), the propeller pitch-diameter ratio (P/D), the rudder wake fraction (WRO), and the propeller wake fraction (WPO). Table 5-27 summarizes the range of each variable for both vessels.

Variable	M.V. "Algowest"	M.V. "Atlantic Freighter"
BAR	0.5 - 0.8	0.5 - 1.0
P/D	0.7 - 1.0	0.7 - 1.2
WRO	0.3 - 0.5	0.05 - 0.3
WPO	0.3 - 0.5	0.05 - 0.3

Table 5-27: Range of Variables for Sensitivity Analysis

The analysis was carried out for the turning circle manoeuvre and the $10^{0}/10^{0}$ zigzag manoeuvre, using the M.V. "Algowest" in both operating conditions, and the M.V. "Atlantic Freighter". To explain how the results of this analysis were derived, the example of the turning circle manoeuvre for the M.V. "Algowest" can be examined.

The first computer simulation was executed using the ship data as recorded in this report, (see section 5.3 and Appendix D). Next, one of the selected parameters was varied within the ranges listed in Table 5-27 and the results of the simulation were recorded again.

For example, the blade area ratio was changed from its initial value of 0.5 to 0.6 and the simulation was rerun. The values of the parameters for the turning circle manoeuvre were recorded and compared to the values of the original simulation. The percentage difference between these values was then calculated and used to generate the figures found in this section of the report. This process was repeated using the entire range of the blade area ratio, and then the next parameter (pitch-diameter ratio) was varied, etc.

Using the procedure outlined in the preceding paragraphs, a series of graphs were generated which illustrated the sensitivity of the simulation results to each of the selected input parameters. Figures 5-22 and 5-23 illustrate the variation of the turning circle manoeuvre characteristics when each of the four input parameters were altered for the M.V. "Algowest" in the loaded conditions. The blade area ratio (BAR) had a significant effect on the final speed, however, the remaining parameters varied less than 10% from the original value. The pitch diameter ratio (P/D) affected all results by more than 20%, except for the final speed which changed less than 10%. It is significant to note that the steady turning diameter was altered by 31% within

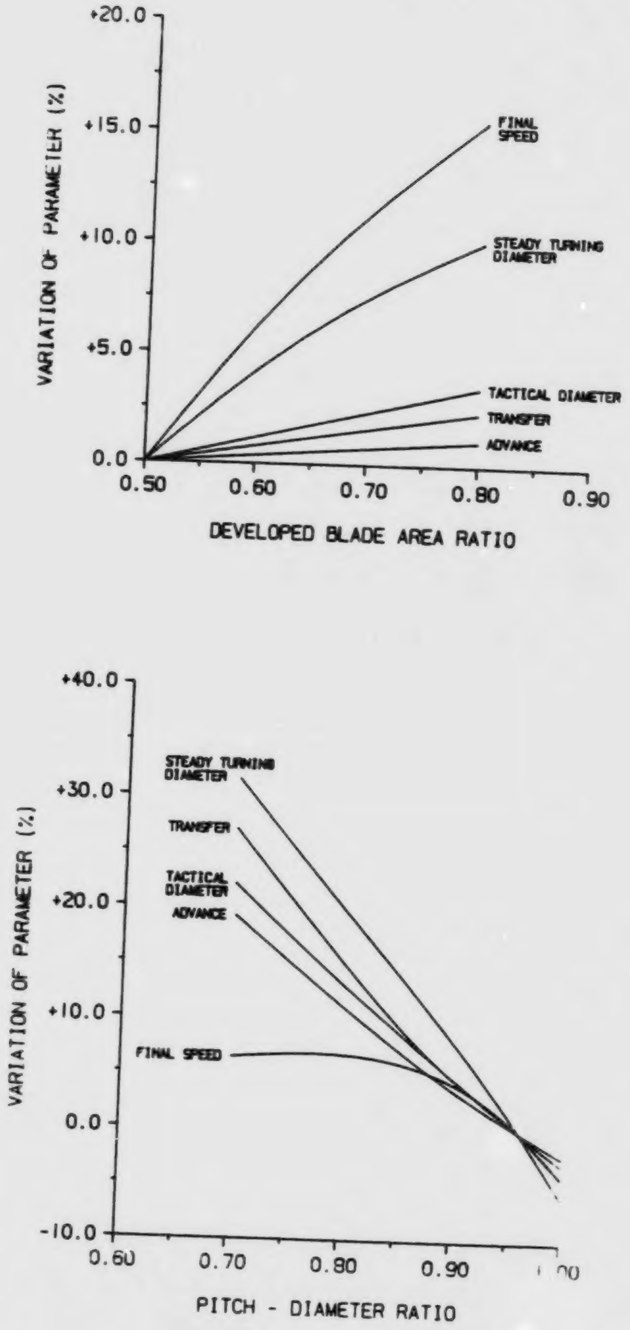


Figure 5-22: The Effect of Blade Area Ratio and Pitch-Diameter Ratio - M.V. "Algowest" Loaded Condition, Turning Circle Manoeuvre

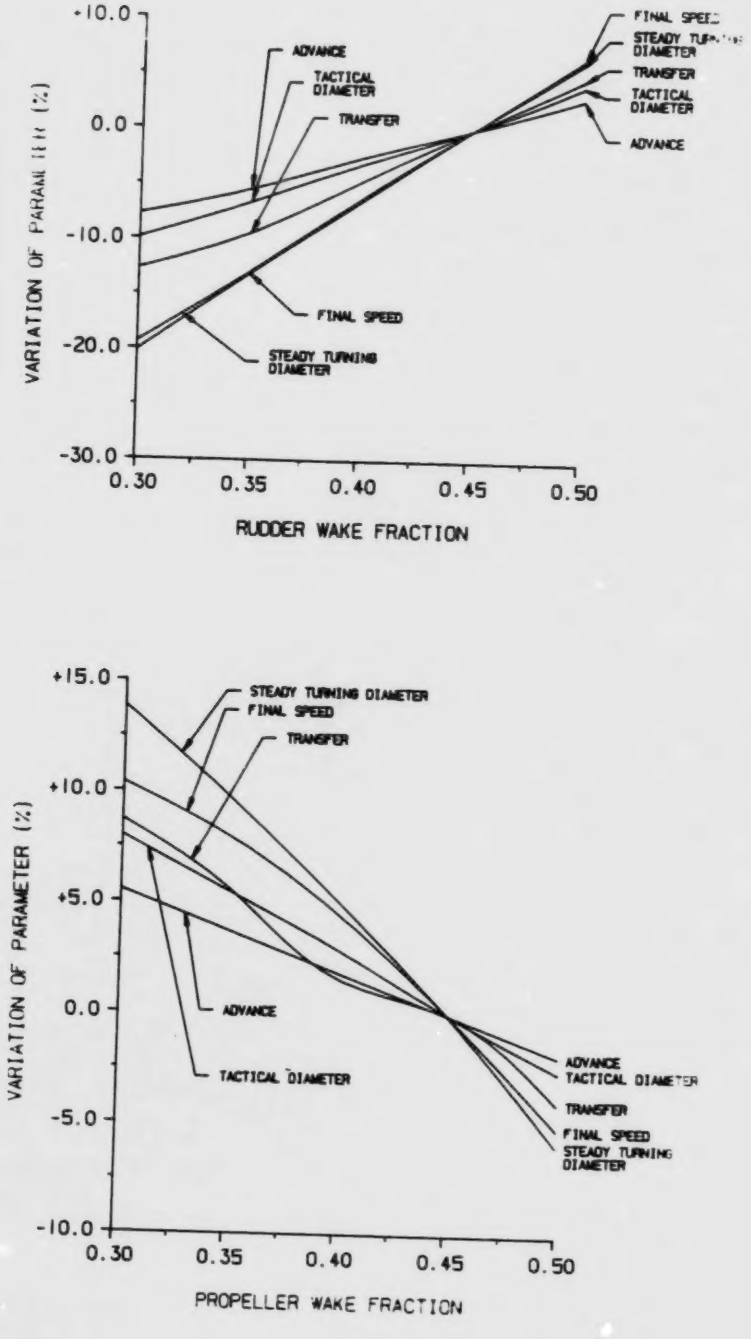


Figure 5-23: The Effect of Rudder Wake Fraction and Propeller Wake Fraction - M.V. "Algowest" Loaded Condition, Turning Circle Manoeuvre

the range of P/D which was used.

The rudder wake fraction (WRO) significantly influenced the final speed, transfer and steady turning diameters, and the propeller wake fraction (WPO) also altered the steady turning diameter and final speed greater than 10% of its original value.

For the $10^{o}/10^{o}$ zigzag manoeuvre (refer to Figures 5-24 and 5-25) the BAR did not have an impact on the simulation results. This was also true for the WPO, however the WRO did alter the overshoot width of path more than 15% and the period and reach by an amount greater than 10%. The most significant influence on the zigzag manoeuvre was produced by P/D. This parameter altered the overshoot angle greater than 10%, the overshoot width of path by 34%, the period by 37% and the reach by 25%.

When the simulations for the M.V. "Algowest" were executed using the ballast condition, it was determined that the BAR did not significantly influence the turning circle parameters or the zigzag parameters. The P/D affected all parameters for both manoeuvres except the final turning speed and the overshoot width of path. The other parameters were altered by a minimum of 20% and a maximum of 33%.

The WPO altered the transfer, tactical diameter, steady turning diameter and overshoot angle by amounts greater than 10%. All parameters of the turning circle and zigzag manoeuvvres were changed by more than 10% when WRO was varied. Figures 5-26 to 5-29 illustrate the sensitivity analysis results for the M.V. "Algowest" in the ballast condition.

For the M.V. "Atlantic Freighter", the variation of BAR did not have an effect on the turning circle manoeuvre or the $10^{o}/10^{o}$ zigzag manoeuvre. In contrast, the P/D had a significant influence on all of the parameters for both manoeuvres. These

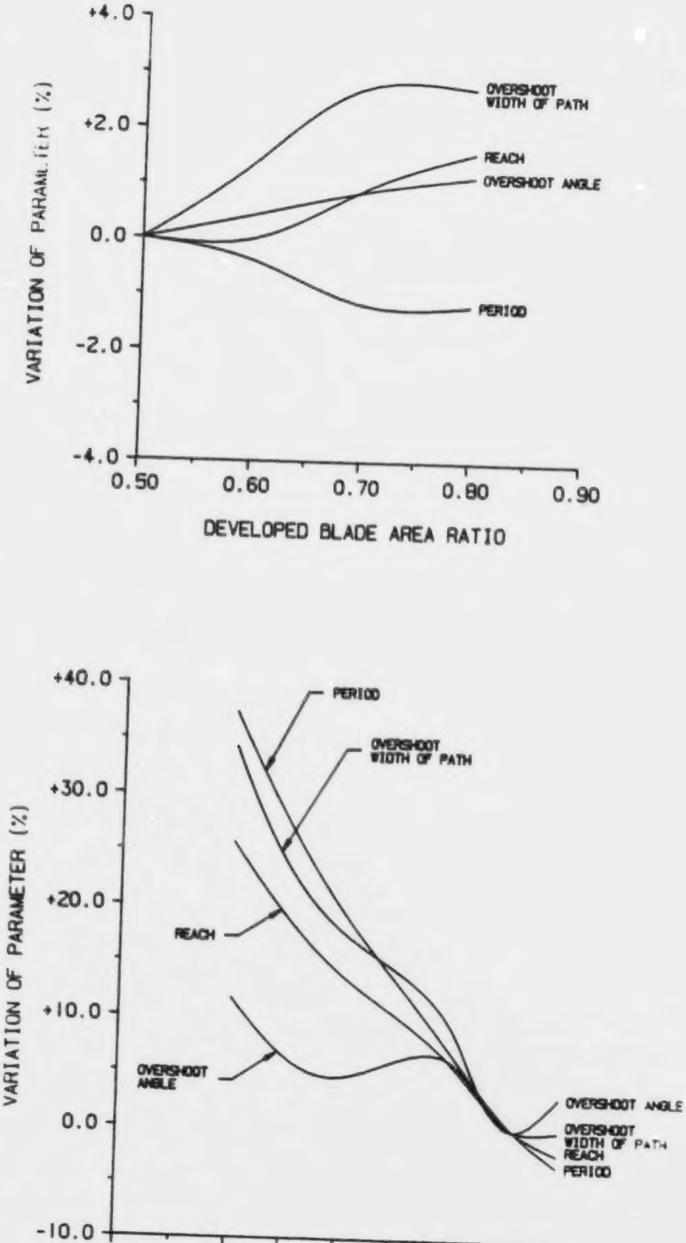
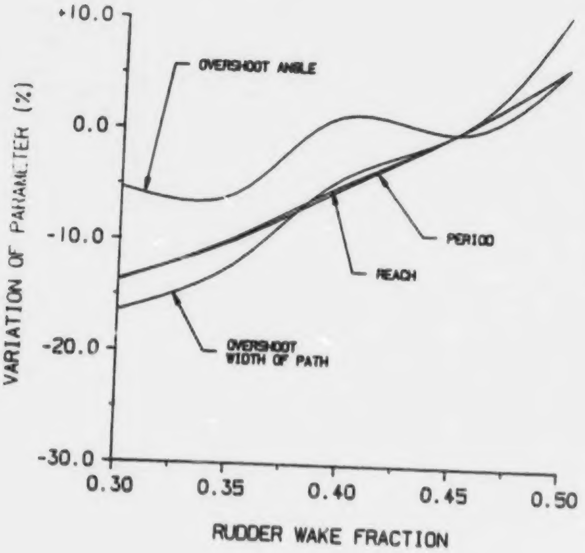


Figure 5-24: The Effect of Blade Area Ratio and Pitch-Diameter Ratio - M.V. "Algowest" Loaded Condition, $10^{0}/10^{0}$ Zigzag Manoeuvre



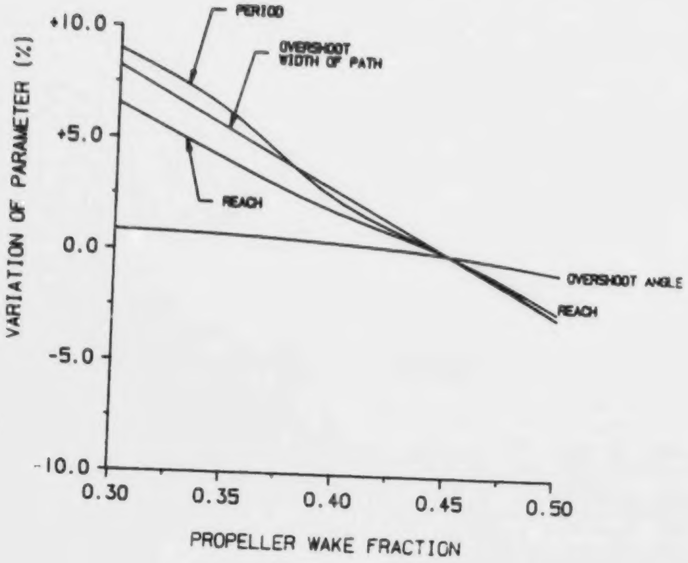


Figure 5-25: The Effect of Rudder Wake Fraction and Propeller Wake Fraction - M.V. "Algowest" Loaded Condition, 10°/10° Zigzag Manoeuvre

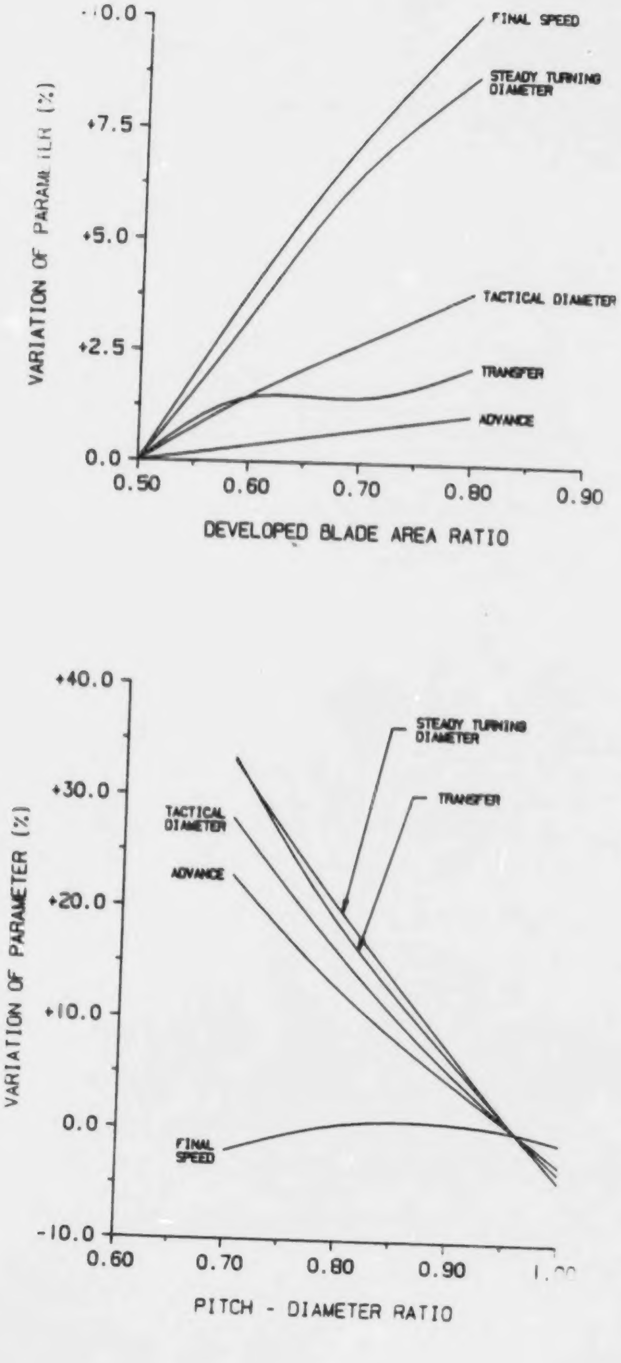


Figure 5-26: The Effect of Blade Area Ratio and Pitch-Diameter Ratio - M.V. "Algowest" Ballast Condition, Turning Circle Manoeuvre

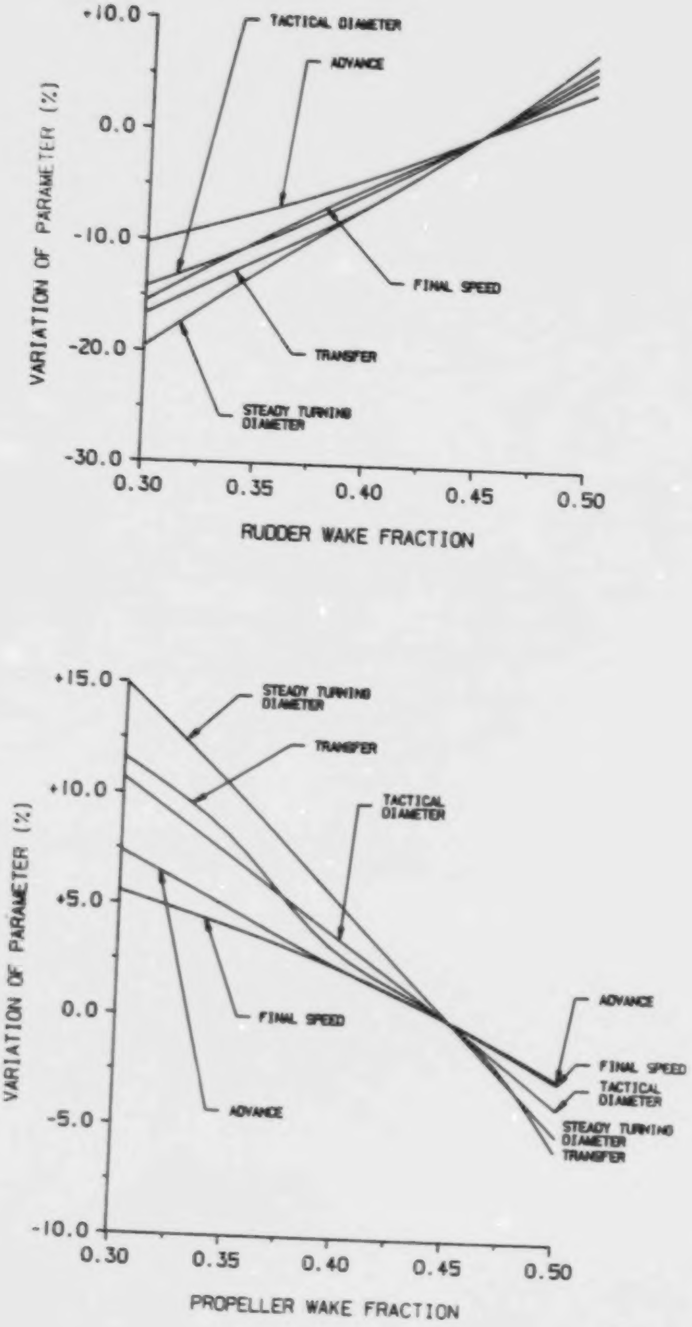


Figure 5-27 : The Effect of Rudder Wake Fraction and Propeller Wake Fraction - M.V. "Algowest" Ballast Condition, Turning Circle Manoeuvre

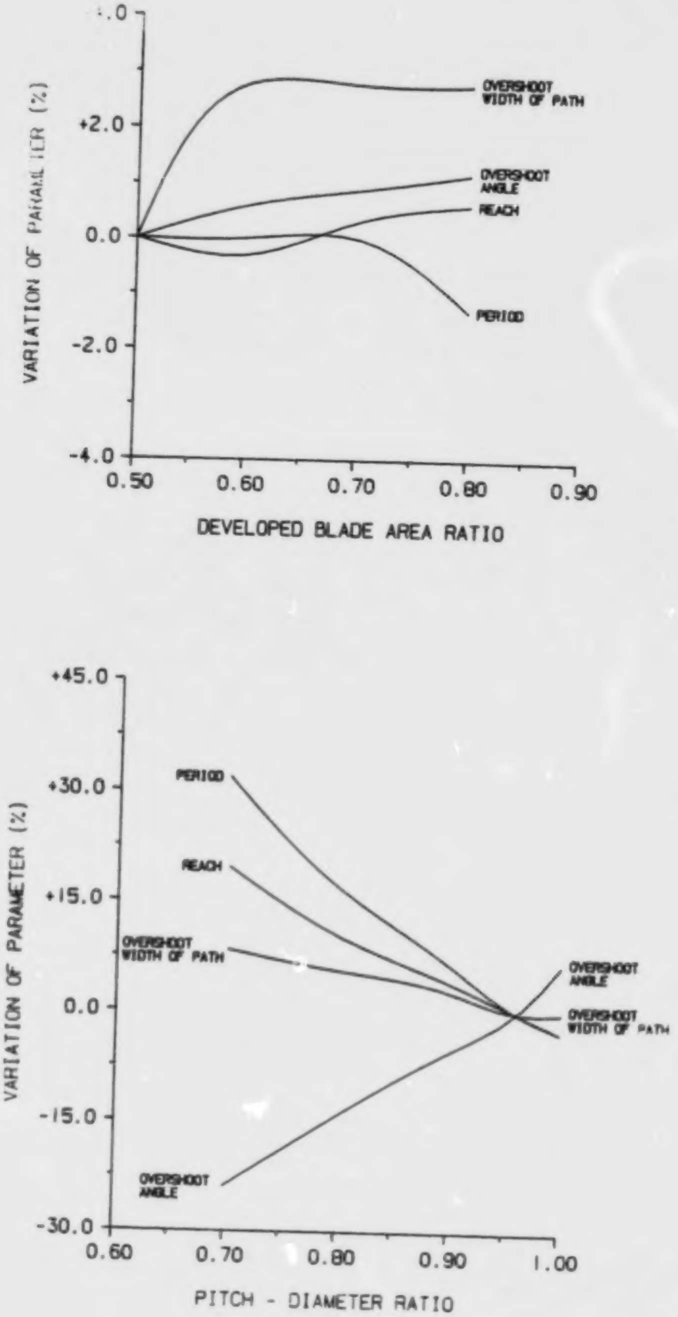


Figure 5-28: The Effect of Blade Area Ratio and Pitch-Diameter Ratio - M.V. "Algowest" Ballast Condition, $10^0/10^0$ Zigzag Manoeuvre

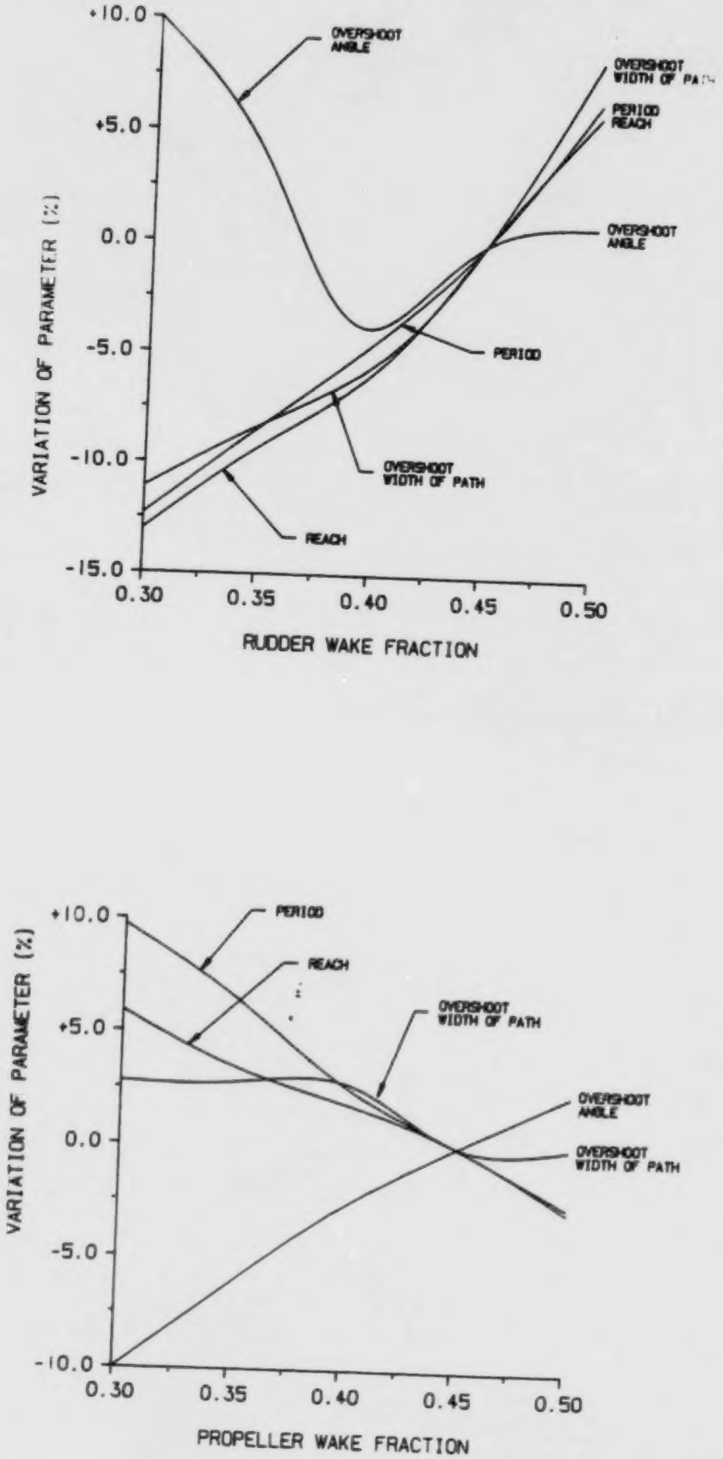


Figure 5-29 : The Effect of Rudder Wake Fraction and Propeller Wake Fraction - M.V. "Algowest" Ballast Condition, $10^0/10^0$ Zigzag Manoeuvre

results are presented in Figures 5-30 and 5-31.

The WPO only affected the overshoot angle and period, however the WRO had an impact on almost all of the measured parameters for each manoeuvre. The only exceptions were the final speed of the turning circle manoeuvre and the overshoot angle of the zigzag manoeuvre. Figures 5-32 and 5-33 summarize the results of the analysis.

Table 5-28 presents a summary of all manoeuvring parameters which were altered by more than 10% when one of the sensitivity analysis variables was changed. Both the pitch-diameter ratio and rudder wake fraction were the variables which produced the largest changes in the simulation results.

The pitch diameter ratio is one of the propulsion parameters that a naval architect will vary during the initial stages of a design. Therefore, this computer model must undergo refinements to reduce its sensitivity to P/D and produce more reliable results, if it is to be used as a design tool during the preliminary design phase as the original author (ref. 1) had intended.

The rudder wake fraction is a very difficult parameter to quantify given the complex flow interactions which occur at the rudder. During the course of this study, it was set equal to the value of the propeller wake fraction, which is also difficult to quantify, particularly during the initial stages of a design. It was shown that this parameter had a significant impact on the results of the simulation and therefore the model must also be desensitized to WRO.

At this point in time the sensitivity of the model to the aforementioned parameters must be recognized as a limitation.

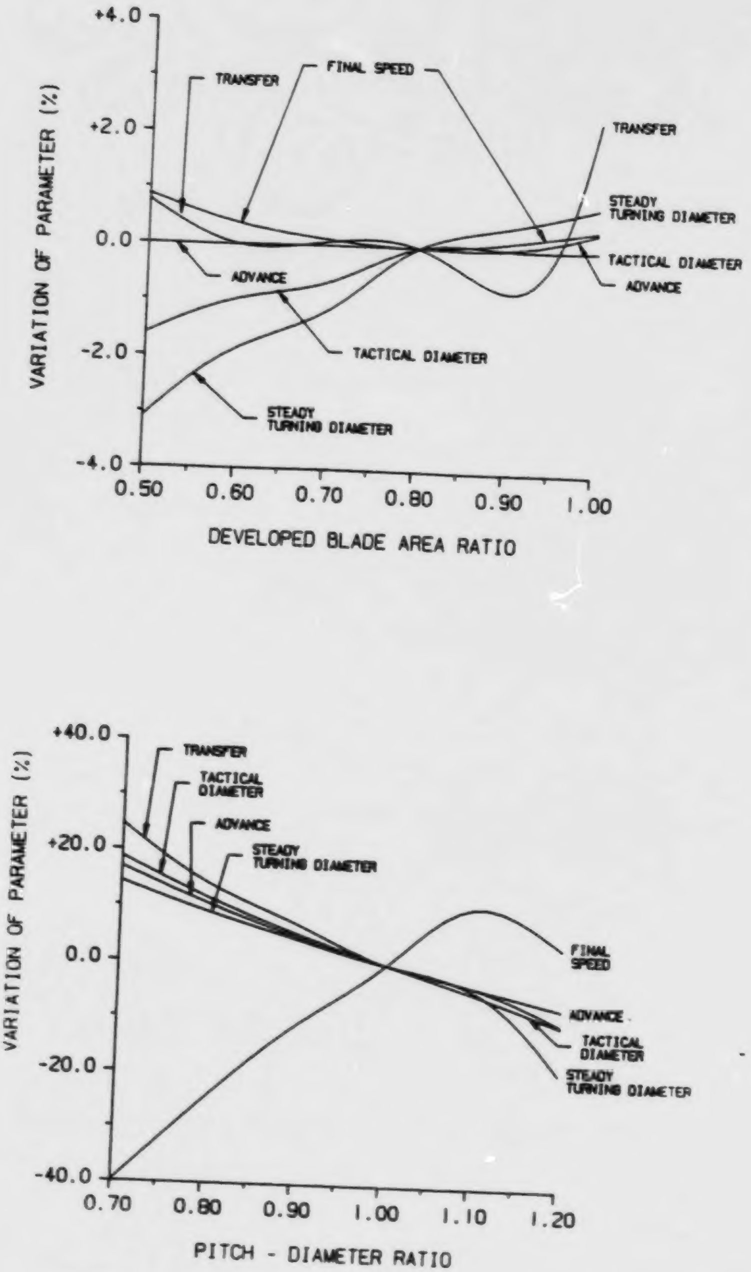


Figure 5-30: The Effect of Blade Area Ratio and Pitch-Diameter Ratio - M.V. "Atlantic Freighter", Turning Circle Manoeuvre

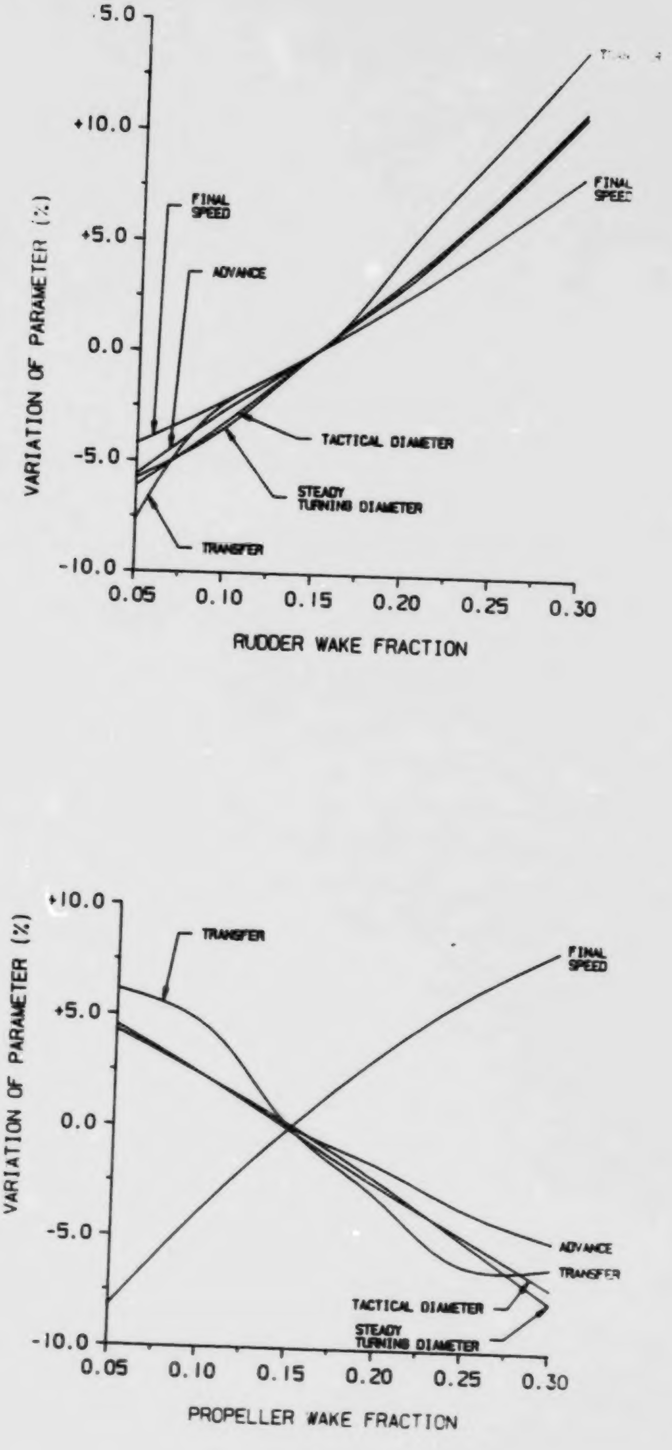


Figure 5-31 : The Effect of Rudder Wake Fraction and Propeller Wake Fraction - M.V. "Atlantic Freighter", Turning Circle Manoeuvre

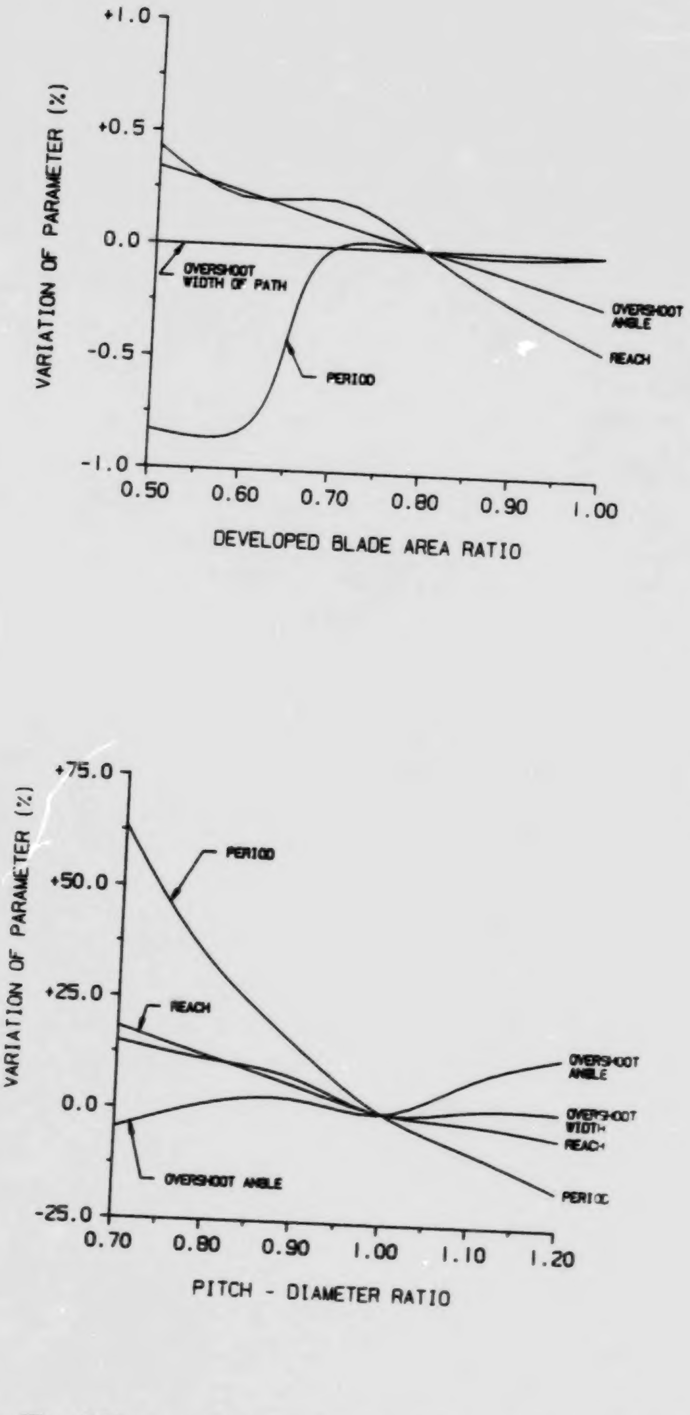
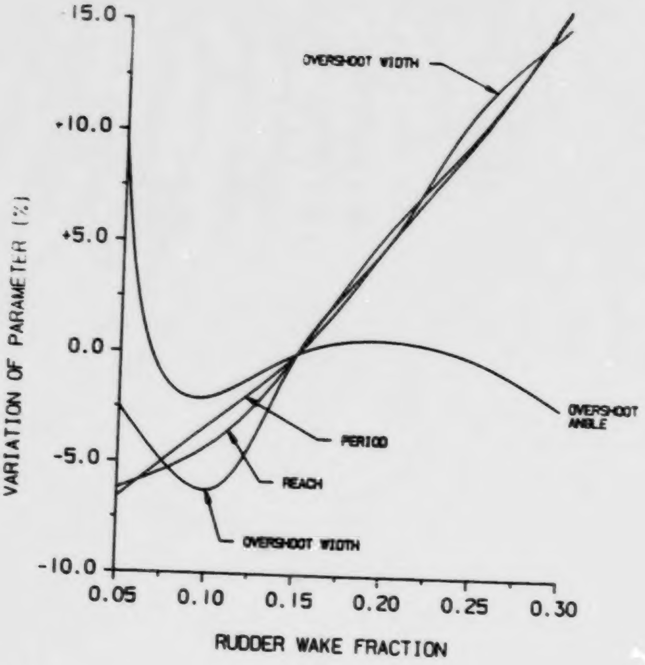


Figure 5-32: The Effect of Blade Area Ratio and Pitch-Diameter Ratio - M.V. "Atlantic Freighter", $10^0/10^0$ Zigzag Manoeuvre



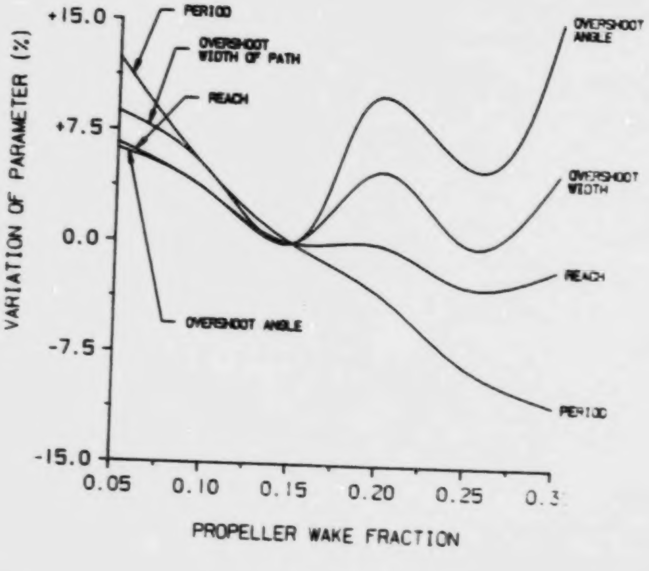


Figure 5-33 : The Effect of Rudder Wake Fraction and Propeller Wake Fraction - M.V. "Atlantic Freighter", 10°/10° Zigzag Manoeuvre

	M.V. "ALGOWEST" (LOADED)				M.V. "ALGOWEST" (BALLAST)				M.V. "ATLANTIC FREIGHTER"			
PARAMTER	BAR	P/D	WRO	WPO	BAR	P/D	WRO	WPO	BAR	P/D	WRO	WPO
Final Speed	*		*	*	*		*			*		
Advance		*				*	*			*	*	
Transfer		*	*			*	*	*		*	*	
Tactical Diameter		*				*	*	*		*	*	
Steady Turning Diameter		*	*	*		*	*	*		*	*	
Overshoot Angle		*				*	*	*		*		*
Overshoot Width		*	*				*			*	*	
Period		*	*			*	*			*	*	*
Reach		*	*			*	*			*	*	

* indicates that the input variable (BAR, P/D, WRO, WPO) altered the parameter by an amount greater than 10% of its original value.

Table 5-28: Sensitivity Analysis Summary

5.4.3 Limitations of the Computer Model

The inherent limitations of the computer model, with respect to the range of validity for the empirical formulae used in the program, were summarized in Table 5-1 of this report. If an estimate of the turning circle characteristics for a particular vessel is required, and the vessel's dimensions are not within the data limits, the accuracy and reliability of the results may be adversely affected. However, one must not reject the results entirely without first using discretion and at least one other prediction method. It is for these reasons that the computer program only issues a warning message when one or more of the input parameters does not meet the limits of the empirical formulae, instead of terminating the computer program.

The main theoretical method used in the model itself has certain limitations, principal among which is that the hydrodynamic derivative calculations are developed for single screw, single rudder ships. An approximate twin screw, twin rudder correction has been developed but other configurations cannot be handled at present.

Both the resistance model and the propeller model are based on standard series. Should either the ship or the propellers be unusual in form then the methodology may again give misleading results. The ability to substitute more appropriate data from trials on similar ships has been left open (see Section 5.1) but needs to be used intelligently if chosen.

From the results of the computer simulations for the M.V. "Atlantic Freighter", it was apparent that the approximation used for modelling twin screw ships was not wholly adequate. Further work is required in this area, however, the current results show that the model is capable of providing reasonably accurate results and of clearly identifying trends.

The sensitivity analysis clearly identified the pitch diameter ratio and rudder wake fraction as the two variables which had the greatest impact on the simulation results. The model's sensitivity to these two parameters is a limitation, given the uncertainity that is associated with P/D and WRO during the early stages of a design.

5.4.4 Comparisons with Manoeuvring Database

The results obtained from the simulations, the full-scale trials, and the sensitivity analysis have been compared with the information collated during an earlier project (Ref. 23) to form the Canadian manoeuvring database. The two ships tested are themselves contained in this database, but are not identified by name. Therefore, no direct comparison has been made between old and new sea trials results.

Two data subsets generated from the database covered lakers and ferries respectively. Tactical turning diameter and crash stop headreach are available for most of the vessels; data on other manoeuvring parameters is sparse. For both subsets, mean performance in these manoeuvres was determined, as was the standard deviation about this line, shown in Figures 5-34 to 5-37. The highlighted points on each graph show the new trials results and the simulation results for the ships tested in this project.

The figures emphasize the amount of scatter in the database. Comparing this even with the range of variation shown by the sensitivity analysis it is difficult to avoid concluding that many of the points are unreliable, and likely affected by environmental conditions or inaccurate measuring techniques.

If the individual points are of low quality, the same will be true of the statistical data derived from them. This is of particular importance because certain researchers and national authorities (e.g., Ref. 31) have proposed the use of similar data sets to establish international minimum performance standards.

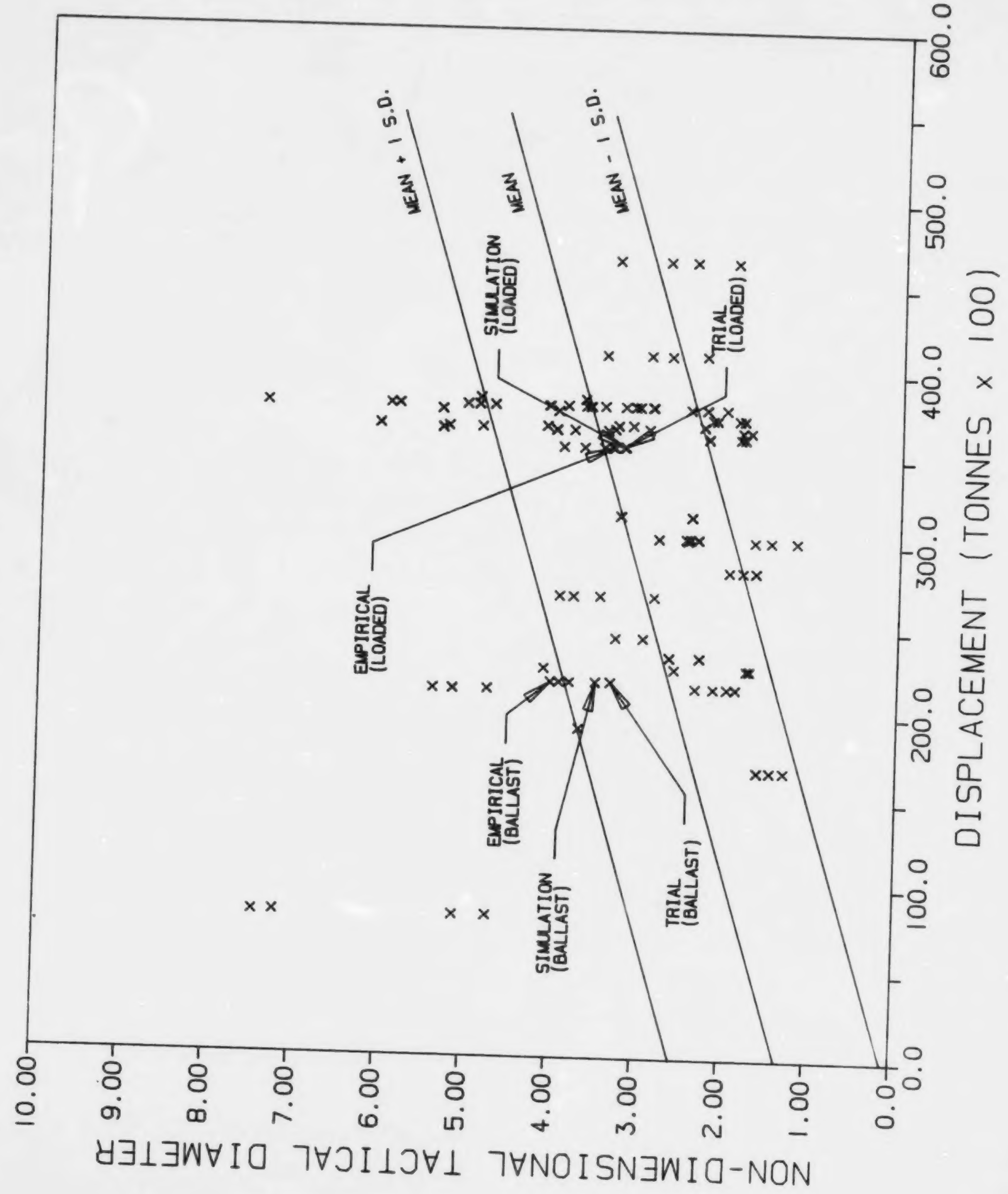


Figure 5-34: Laker Turning Circles (from Database)

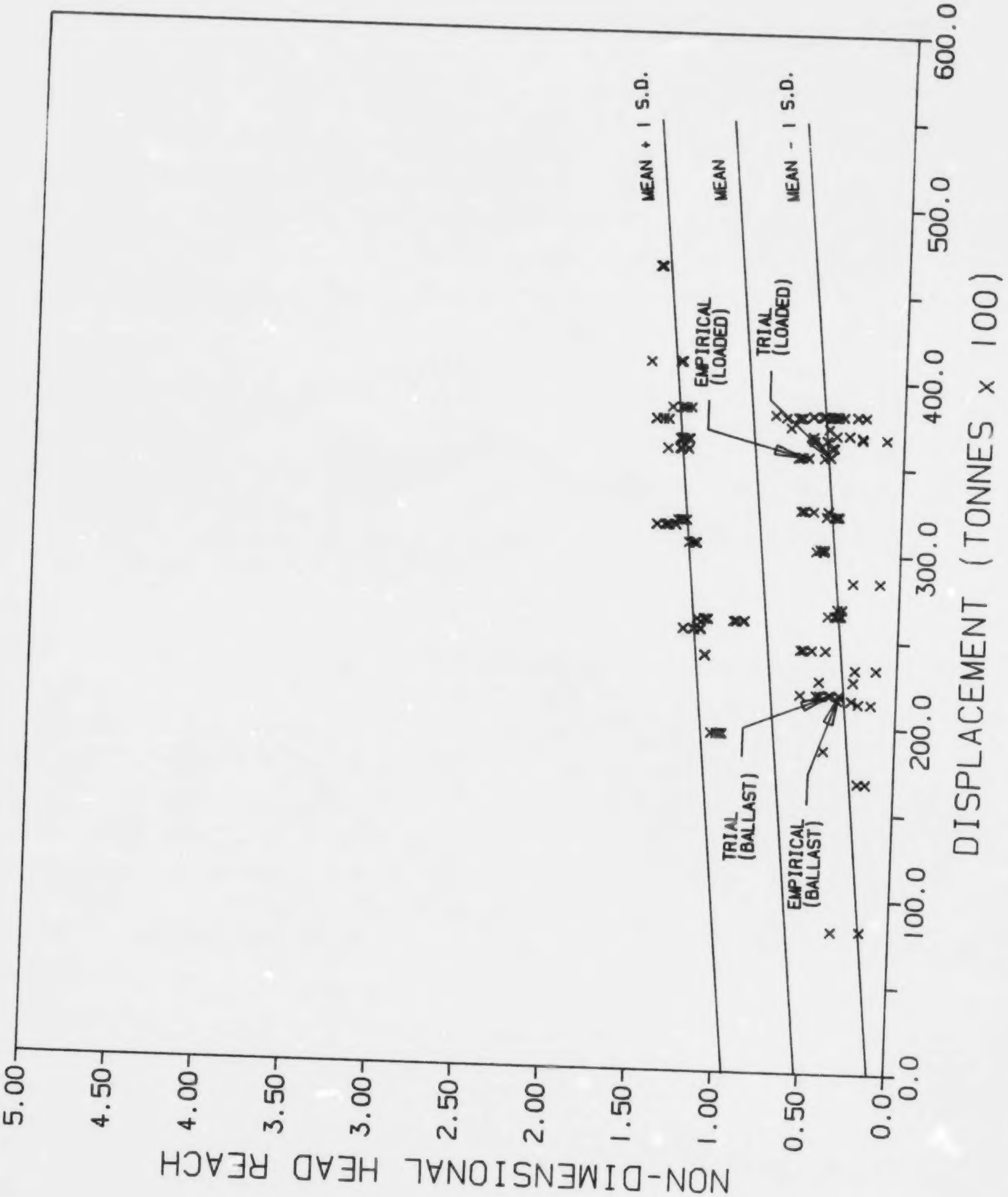


Figure 5-35: Laker Crash Stops (from Database)

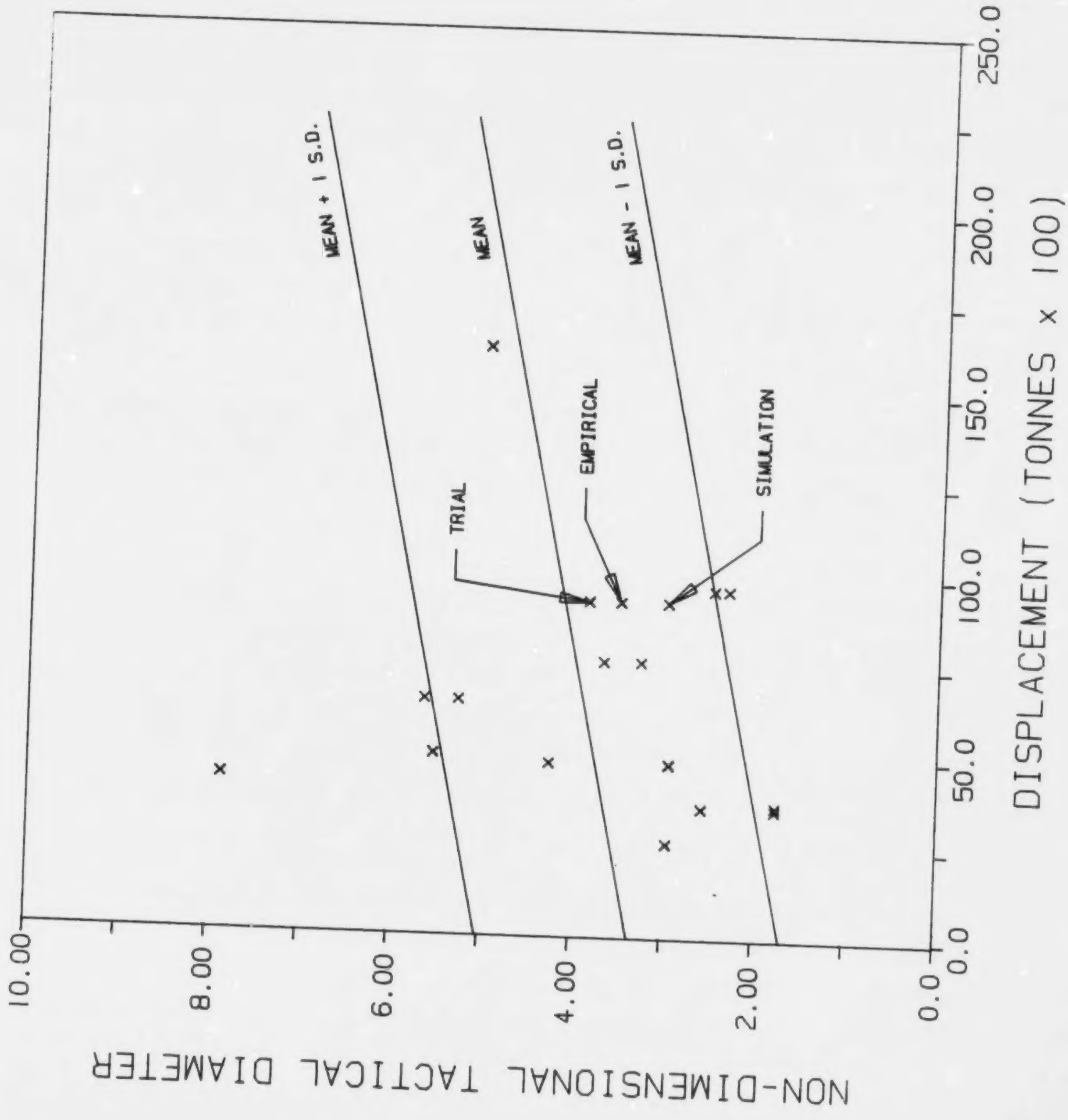


Figure 5-36: Ferry Turning Circles (from Database)

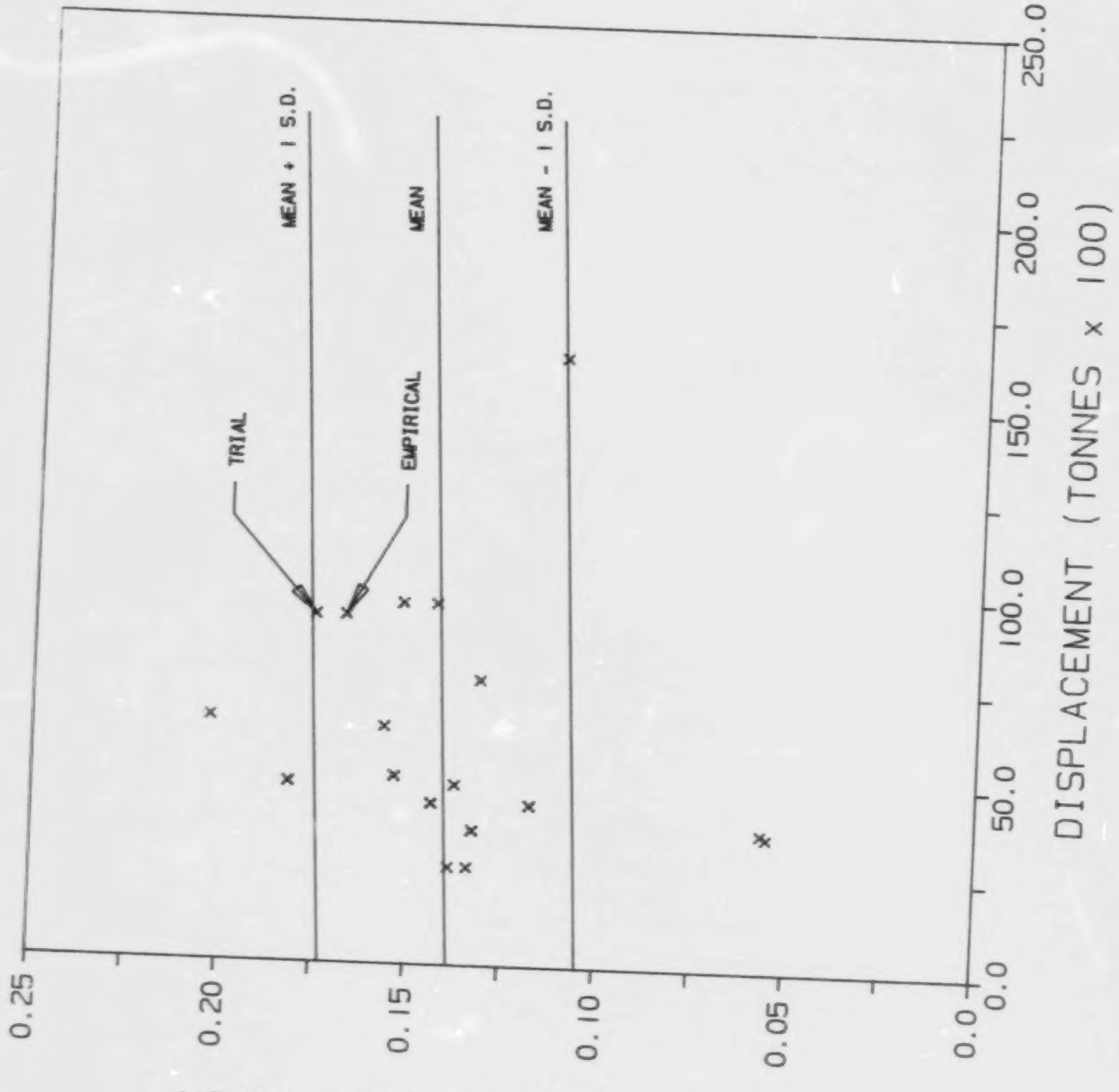


Figure 5-37: Ferry Crash Stops (from Database)

6.0 COMPUTER PROGRAM TRAINING PLAN

The computer program which was developed for this project is very user-friendly. It is not an interactive program, therefore, the user must ensure that input data file is correct before the program is executed. To review the algorithms used in the program, and to discuss the program structure and capabilities in detail, German & Milne Inc. has developed a training seminar for handover of the program to any organization which wishes to make use of it. The topics that are covered include:

- background information;
- research effort;
- description of time domain simulation;
- description of empirical methods;
- operating procedures;
- miscellaneous information; and
- program demonstration.

(A full agenda is included in Appendix "C" of this report).

The seminar is of approximately 4 hours duration, and provides the trainees with a in-depth description of the complete software package and the operating procedures. However, it is assumed that the trainees will be familiar with the Micro-Vax/VMS operating systems, at least to the extent of being able to logon/log-off, edit files and perform routine file management duties. The ideal class size for the seminar is four (4) to six (6) people.

One copy of the User Manual (ref. 16) is made available to all trainees prior to the date of the seminar.

7.0 RECOMMENDATIONS FOR FUTURE WORK

7.1 STANDARDIZATION OF SEA TRIALS

The seas trial program developed during this project and described in Section 3.0 should be used to form the basis of requirements or guidelines promulgated by the Canadian Coast Guard, Ship Safety Branch. This will ensure that all new vessels built in Canada or for operations in Canadian waters have available consistent data to describe their manoeuvring performance. Both immediate safety considerations and the future development of national and international standards and regulations dictate that data collected be accurate and comprehensive.

The introduction of a standardized trials program to the Canadian Marine Industry should incorporate a number of steps taken to inform and involve those who will be affected by the policy - naval architects, shipbuilders, shipowners, seafarers and pilots. The approach taken could include:

- information dissemination, providing explanations and descriptions of the proposed program to interested parties.
- solicitation of feedback from industry and from within government.
- analysis of feedback to identify areas of legitimate concern and modifications which could eliminate or reduce perceived problems.
- explanation to respondents of the reasons for any changes made to the original proposals.

A variety of mechanisms could be used to undertake these activities, for example direct mail, presentations/seminars, the preparation of articles for industry journals, etc.

7.2 REFINEMENT OF MATHEMATICAL MODEL

7.2.1 Ship Configuration

Many of the components of the mathematical model developed in this project have a limited range of validity, or rely on the input of parameters whose values are only easily estimable for certain ship configurations. This has been discussed in Section 5.0, and should be borne in mind by any future user of the software.

The software development for this project has deliberately used a modular approach, to allow upgrading and/or easy integration of additional subroutines. Elements which could be added or improved using programs which already exist or which could be relatively easily developed include: preliminary propeller design routines; resistance models of wider applicability; and engine/shaft speed simulation programs. Development or purchase of such software fell outside the scope of this project, but should be considered if it is intended to keep the current mathematical model abreast of the state of the art.

Some other aspects of the model are less tractable using simple or standard formulae. Examples of this are the propeller and rudder wake fractions, whose importance was highlighted by the sensitivity analysis. Values for these parameters are available within reasonable confidence limits for only a restricted range of ship types and aft end forms. Physical models or complex fluid dynamic mathematical analyses are currently needed to establish accurate wake fractions for other vessels. Considerable data on wake fractions does exist by virtue of the many wake surveys conducted on ship models over the years. It would be a valuable objective for future research projects to collate and systematically analyze this information. It could then be reduced to a format from which naval architects could extract good approximate values for use in the early iterations of any design or for design check purposes. Such data would be useful not only for manoeuvrability investigations, but also for a variety of other calculations including propeller selection and noise and vibration analyses.

The current manoeuvring model has not been tested against ships with a number of less common but increasingly popular propeller/rudder configurations. It may prove to provide reasonable estimates of performances for certain of these in cases where the naval architect can identify accurate similar ship data for the key input parameters. In other cases the explicit and implicit assumptions on which the questions of motion and force derivations are based will not be valid, and the model cannot be expected to yield useful results without modifications. Listed in descending order of applicability of the model, some configurations sufficiently widely used to warrant further investigation include:

- twin propeller/single rudder
- high lift rudders (e.g. flapped, Becker type)
- fixed nozzles
- active rudders (e.g. rotating cylinder)
- steerable nozzles
- azimuthing thrusters

For a majority of these cases, modifications to the program are expected to be relatively straightforward, as the performance characteristics of the devices are well known or easily determined. More complex development work may be needed where flow interactions are less obvious, as in the case of active rudders or with certain types of nozzles.

7.2.2 Environmental Effects

It is increasingly widely recognized that manoeuvring performance in unrestricted waters is of limited relevance to the majority of scenarios in which such performance is important. Most manoeuvres are required in areas where water depth and/or channel width are limited. Under such conditions, the manoeuvring characteristics of ships can change dramatically, and the relative open water performance of two ships does not necessarily reflect their relative ranking in these circumstances.

Restricted waters influence all aspects of fluid flow around the ship, and a set of complex and subtle interactions must be accounted for in any theoretical or model scale investigation and analysis of the problem. The development of a general solution to this problem will require an extensive program of research and development. Some necessary components of this have already been identified in discussions between several representatives of Canadian industry and government organizations including Transport Canada and the National Research Council.

Since restricted water effects are so fundamental to most manoeuvres, it is considered that no national or international imposition of standards for manoeuvring performance should be supported until these effects are better understood. As there is increasing pressure from several national administrations to introduce such standards, research and development into this area of manoeuvrability should be accorded high priority.

Another important influence on manoeuvrability is wind. Many high-sided ships become unmanageable at low speeds in strong winds, and a number of casualties have been influenced by wind effects. It may thus be equally inappropriate to standardize manoeuvrability requirements on the basis of calm wind conditions as it is on deep water conditions. Similar fluid mechanics formulations to those used elsewhere in the existing mathematical model can be used to account for wind effects, and an additional module for the program could be developed to include them.

7.2.3 Physical Testing

Any extension of this (or any other) mathematical modelling technique should be accompanied by additional physical testing at full or model scale. Equally, any accurate physical tests undertaken for design development, contractual, or other purposes can be used as a basis for further validation of software. In the event that TDC, CCG or other interested government agencies sponsor or undertake suitable manoeuvring tests, it may be worthwhile to use these as opportunities to extend the manoeuvring software. Examples of such trials may include the Coast Guard's PAPA trials series, and work conducted in support of precise navigation system development by the Departments of Transport and of Fisheries and Oceans. As a minimum, results of such trials should be incorporated in the manoeuvring data base established by CCG/SSB.

8.0 CONCLUSIONS

8.1 GENERAL

The principal project objective established by the Statement of Work was defined as:

> "To develop a standard methodology applicable to determination of the manoeuvring performance of the Canadian fleet, and thus to establish a strong Canadian position for international negotiations regarding ship manoeuvring standards".

Both components of this objective have been achieved. However, the results of the project have shown that in general, prediction of manoeuvring performance with accuracy adequate for regulatory purposes cannot be guaranteed using readily available computational techniques. In German & Milne's view, this means that more work is needed before Canada can give its support to the establishment of international manoeuvring performance standards.

8.2 Standardization of Sea Trials

A premise for this project was that if manoeuvring data is to be displayed aboard ships for the information of and use by crews, pilots and others, then this data should be collected using standardized, accurate and repeatable trials.

A number of standard sets of trials have been proposed by various groups. This project has developed a "Sea Trials Program" (refer to Section 3.0), selected from these trials and trials procedures, which will provide all information required for shipboard display under IMO Resolution A209. The majority of these procedures have been tested as an incidental element of other tasks involved in the project, and have proven to be easily and rapidly achievable under several sets of circumstances. We have concluded that following such standardized procedures will represent a marginal increase in cost to shipowners, and that the benefits relating to reduced risk of collisions or other accidents are considerably more significant.

8.3 Mathematical Modelling

Sea trials can accurately determine the performance of a ship only after it has been completed, and when few measures can be taken to alter its characteristics. There is more potential to use physical model tank test results to modify a design, but the need to undertake such tests can increase the duration and cost of the design process. The impact of imposing manoeuvring performance standards will therefore be considerable, unless relatively simple and adequately accurate analytical methods of preliminary performance prediction can be developed.

This project aimed to identify whether the current state of the art in manoeuvrability analysis can meet these requirements. The results obtained suggest that it cannot. The best of the current methodologies has serious limitations in the range of vessels to which it can be applied, and requires inputs of data which is not always available at the early stages of design. However, this project has succeeded in developing a mathematical model which can make a useful contribution to the design process of certain types of vessel. It can also be of considerable use in predicting the behaviour of existing ships whose particulars are known but whose performance may not have been adequately trialled or in developing solutions for improving the characteristics of such ships. The model also provides a firm base for further research and development effort.

8.4 Manoeuvring Standards

The absence of convenient prediction techniques is a good but not necessarily sufficient reason for not supporting the introduction of standards. If the risks associated with inadequate performance are high enough, it may be justifiable to impose on the industry the costs associated with overdesign or operational restriction.

This project has reinforced the opinion of the authors that the risks associated with inadequate manoeuvring performance have not been quantified in a way which provides such justification; and that as a corollary no good definition of adequacy in manoeuvrability has yet been proposed. Many accidents are undoubtedly influenced by manoeuvrability, but usually in circumstances where the performance measured in standard tests gives limited insight into the probable response of the ship; for example in shallow waters or with significant winds. Regulation, if necessary, should be based on probable behaviour in these conditions. This will require greater insight than currently exists into the prediction of manoeuvrability.

The manoeuvring-related standards introduced to date by some national authorities and reflected in IMO Resolution A209 require the display of performance data aboard all large ships. Re-examination of the database of manoeuvring information currently carried aboard Canadian ships (Ref. 23) in the light of both the trials and the simulations conducted during this project has reaffirmed the premise stated in Section 8.2 of this report that if such information is required, it must be collected by internationally standardized and nationally regulated procedures. Much of the data currently provided may be inaccurate and misleading, and thus counter-productive in terms of increasing safety of navigation.

8.5 Canadian Position for International Negotiations

As part of this project, a submission to the International Maritime Organization (IMO) was prepared summarizing the objectives and results, and drawing conclusions relevant to the IMO's initiatives. This is attached in full as Appendix G to this report.

The conclusions presented reflect those discussed above. Canada has outlined a number of concerns associated with moves towards regulation of manoeuvring performance, and has proposed additional steps that need to be taken before standards are introduced. The remainder of the submission demonstrates that the Canadian position is firmly based on theoretical and practical work, and therefore warrants full and serious consideration.

9.0 REFERENCES

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APPENDIX A

BIBLIOGRAPHY AND ABSTRACTS

1). Inoue, S.; et al; "A Practical Calculation Method of Ship Manoeuvring Motion", International Shipbuilding Progress, Vol. 28, No. 325, May 1981.

Abstract

This paper presents a practical calculation method of the ship maneuvering motion using the principal particulars of ship hull, propeller and rudder as basic input data. The mathematical model, which describes the ship maneuvering motion, is developed employing the coupled equations of surge, sway, yaw,roll and propeller revolution. Computations are made for various kinds and types of the merchant ships and for wide range of the maneuvering characteristics. The computed results show satisfactory agreements with the full-scale trial results. In addition, as an application study, the effect of the loading condition on the ship maneuverability is investigated through the simulation calculations. The conclusion is that the calculation method of the present study is very useful and powerful for the predictions of the ship maneuverability at the time, such as the initial design stage etc., when the principal particulars of ship hull, propeller and rudder are known.

2). Inoue, S., Hirano, M. and Kijima, K.; "Hydrodynamic Derivatives on Ship Manoeuvring", International Shipbuilding Progress, Vol. 28, No. 321, May 1981.

Abstract

This paper highlights model experiments which have been carried out to investigate the hydrodynamic forces acting on ship in even keel and trimmed conditions. The relations between this force and load condition of ship were proved, and the linear and non-linear derivatives in manoeuvring mathematical models for fitting the measured results to describe the forces were also examined semi-empirically by using the model tests of various kinds of ships and applying a theoretical approach. Finally, the approximate formulae for practical application in estimation the lateral force and moment on ship in manoeuvring motion.

3). "Design Information on the Ship Manoeuvrability - Part 1", Netherlands Ship Model Basin, Report No. 45931-1-NS, Dec. 1984.

Abstract

In this report a discussion is given about the available information on the determination of the manoeuvrability of a ship in the design stage.

It is found that it will not be possible in the near future to develop manoeuvring design information by means of empirical methods. Better results are expected from manoeuvring predictions obtained from computer simulations as will be discussed in this report.

Further attention is given to the simulation procedure developed by Inoue, et.al The practical merits of this procedure are described for the application by ship designers.

4). "Design Information on the Ship Manoeuvrability - Part 2", Netherlands Ship Model Basin, Report No. 45931-2-NS, Dec. 1984.

Abstract

In this part the results are presented of computer simulations according to Inoue's method as was described in part 1 of this report. Also a discussion is given about the applicability of these results for ship designers. The computer results have been compiled in a system of information presentation to be used in the design stage of a ship.

5). Lyster, C.A. and Knights, H.L.; "Prediction Equations for Ships' Turning Circles", Trans of the North East Coast Institution of Engineers and Shipbuilders, Vol. 95, No. 4, July 1979.

Abstract

Empirical formulae for estimating the parameters of the turning circle manoeuvre are presented for both single screw and twin screw ships. The equations were derived based upon full scale and model test data, available in the public domain. Standard deviations are also provided for each of the estimated parameters. The following parameters can be predicted using the empirical formulae: advance, transfer, tactical diameter, steady turning diameter and steady turning speed.

6). Oosterveld, M.W.C. and Van Oossanen, P.; "Further Computer-Analyzed Data of the Wageningen B-Screw Series", International Shipbuilding Progress, Vol. 22, No. 251, July 1975.

Abstract

In this paper the open-water characteristics of the Wageningen B-series propellers are provided in polynomials for use in preliminary computer ship design studies. These polynomials were obtained with the aid of a multiple regression analysis of the original open-water test data of the 120 propeller models comprising the B-series. All test data was corrected for Reynolds effects by means of an "equivalent profile" method developed by Lerbs. For this Reynolds number effect additional polynomials are given. Criteria are included to facilitate the choice of expanded blade area and blade thickness. Finally, a number of new type of diagrams are given with which the optimum diameter and optimum RPM can easily be determined.

7). Holtrop, J. and Mennen, G.G.J.; "An Approximate Power Prediction Method", International Shipbuilding Progress, Vol. 29, No. 335, July 1982.

Abstract

A statistical method is presented for the determination of the required propulsive power at the initial design stage of a ship. The method was developed through a regression analysis of model experiments and full-scale data available at the Netherlands Ships Model Basin. The application of the method is limited to hull forms resembling the average ship described by the main dimensions and form coefficients used in the method.

8). Holtrop, J.; "A statistical Re-Analysis of Resistance and Propulsion Data", International Shipbuilding Progress, Vol. 31, No. 363, Nov. 1984.

Abstract

This paper provides a means of predicting power requirements. The method provided in a previous analysis, (refer to International shipbuilding Progress, Vol. 29, No. 335, July 1982), was revised by re-analyzing a larger database of test results. The revisions broaden the applicability of the method.

APPENDIX B

WAGENINGEN B-SCREW SERIES DATA

The table below contains the coefficients and exponents for the "K_T" and "K_Q" polynomials of the Wageningen B-Screws Series propellers.

$$K_T \;\hat{}Q = \sum_{s,t,u,v} C_{s,t,u,v} \text{ x } (J)^s \text{x} (P/D)^t \text{x} (A_E/A_O)^u \text{x} (Z)^v$$

POLYNOMIAL K_T

$C_{s,t,u,v}$	s (J)	t (P/D)	u (AE/Ao)	v (Z)
+0.00880496	0	0	0	0
-0.204554	1	0	0	0
+0.166351	0	1	0	0
+0.158114	0	2	0	0
-0.147581	2	0	1	0
-0.481497	1	1	1	0
+0.415437	0	2	1	0
+0.0144043	0	0	0	1
-0.0530054	2	0	0	1
+0.0143481	0	1	0	1
+0.0606826	1	1	0	1
-0.0125894	0	0	1	1
+0.0109689	1	0	1	1
-0.133698	0	3	0	0
+0.00638407	0	6	0	0
-0.00132718	2	6	0	0
+0.168496	3	0	1	0
-0.0507214	0	0	2	0
+0.0854559	2	0	2	0
-0.0504475	3	0	2	0
+0.010465	1	6	2	0
-0.00648272	2	6	2	0
-0.00841728	0	3	0	1
+0.0168424	1	3	0	1
-0.00102296	3	3	0	1
-0.0317791	0	3	1	1
+0.018604	1	0	2	1
-0.00410798	0	2	2	1
-0.000606848	0	0	0	2
-0.0049819	1	0	0	2
+0.0025983	2	0	0	2
-0.000560528	3	0	0	2
-0.00163652	1	2	0	2
-0.000328787	1	6	0	2
+0.000116502	2	6	0	2
+0.000690904	0	0	1	2
+0.00421749	0	3	1	2
+0.0000565229	3	6	1	2
-0.00146564	0	3	2	2

$R_e = 2 \times 10^6$

POLYNOMIAL K_Q

$C_{s,t,u,v}$	s (J)	t (P/D)	u (AE/Ao)	v (Z)
+0.00379368	0	0	0	0
+0.00886523	2	0	0	0
-0.032241	1	1	0	0
+0.00344778	0	2	0	0
-0.0408811	0	1	1	0
-0.108009	1	1	1	0
-0.0885381	2	1	1	0
+0.188561	0	2	1	0
-0.00370871	1	0	0	1
+0.00513696	0	1	0	1
+0.0209449	1	1	0	1
+0.00474319	2	1	0	1
-0.00723408	2	0	1	1
+0.00438388	1	1	1	1
-0.0269403	0	2	1	1
+0.0558082	3	0	1	0
+0.0161886	0	3	1	0
+0.00318086	1	3	1	0
+0.015896	0	0	2	0
+0.0471729	1	0	2	0
+0.0196283	3	0	2	0
-0.0502782	0	1	2	0
-0.030055	3	1	2	0
+0.0417122	2	2	2	0
-0.0397722	0	3	2	0
-0.00350024	0	6	2	0
-0.0106854	3	0	0	1
+0.00110903	3	3	0	1
-0.000313912	0	6	0	1
+0.0035985	3	0	1	1
-0.00142121	0	6	1	1
-0.00383637	1	0	2	1
+0.0126803	0	2	2	1
-0.00318278	2	3	2	1
+0.00334268	0	6	2	1
-0.00183491	1	1	0	2
+0.000112451	3	2	0	2
-0.0000297228	3	6	0	2
+0.000269551	1	0	1	2
+0.00083265	2	0	1	2
0.00155334	0	2	1	2
+0.000302683	0	6	1	2
-0.0001843	0	0	2	2
-0.000425399	0	3	2	2
+0.0000869243	3	3	2	2
-0.0004659	0	6	2	2
+0.0000554194	1	6	2	2

APPENDIX C

COMPUTER PROGRAM TRAINING SEMINAR

PROPOSED AGENDA

ITEM	DURATION
1) Background - Study objectives	5 min.
2) Research Effort - Literature survey - Screening process - Key references	20 min.
3) Time Domain Simulation - Description of equations of motion - Description of individual subroutines	50 min.
4) Empirical Methods - Turning circle estimate - Crash stop estimate	15 min.
5) BREAK	20 min.
6) Operating Procedures - Required data/limitations of program - Data file preparation - Output file format and interpretation	60 min.
7). Miscellaneous Information - Storage requirements - Editing the program	10 min.
8). Demonstration	60 min.

APPENDIX D

LISTING OF COMPUTER PROGRAM
AND
RESULTS OF COMPUTER ANALYSIS

This appendix contains a listing of the main computer program and results for the M.V. "Algowest" and M.V. "Atlantic Freighter" simulations.

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C                   Transportation Development Center
C
C                             Developed by:
C
C                        German and Milne Inc.
C
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C
C*****************************************************************************
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C
C THIS PROGRAM PERFORMS THE FOLLOWING OPERATIONS:
C
C                1) SINGLE/TWIN SCREW SHIP TURNING CIRCLE SIMULATION.
C
C                2) SINGLE/TWIN SCREW SHIP ZIG-ZAG SIMULATION.
C
C                3) SINGLE/TWIN SCREW SHIP SPIRAL SIMULATION.
C
C                4) EMPIRICAL ESTIMATE OF ADVANCE, TRANSFER, TACTICAL
C                   DIAMETER, AND STEADY TURNING DIAMETER.
C
C                5) EMPIRICAL ESTIMATE OF HEAD REACH DURING A CRASH STOP.
C
C (NOTE:  THE SIMULATION IS APPLICABLE TO TWIN SCREW SHIPS ONLY IF THEY
C         ARE FITTED WITH TWIN RUDDERS BEHIND THE SCREWS.)
C
C THE SIMULATION IS BASED UPON THE METHODOLOGY PRESENTED IN THE PAPER:
C Inoue, et.al., "A Practical Calculation Method of Ship Manoeuvring
C Motion", International Shipbuilding Progress, Vol. 28, No. 325, Sept.
C 1981.
C
C THE EMPIRICAL ESTIMATES ARE TAKEN FROM REFERENCES 2 AND 3
C OF THE MAIN REPORT FOR THIS PROGRAM.
C
C DIMENSION ARRAYS
C
        DIMENSION Y(10),F(10),G(10),RTOT(30),RWAVE(30),RAPP(30),RBULB(30)
        DIMENSION RTRAN(30),RCOR(30),RFRIC(30),SPD(30),EHP(30),ARAPP(10)
        DIMENSION K2(10),YAWANG(4000),YWRATE(4000),IERROR(9)
        DIMENSION RESULTS(5),RESSPIR(20)
C
C DECLARE VARIABLES
C
        REAL KVIS,K2,LPP,LWL,M,META,LCB,KXX,KZZ,KT,KQ,JADV
        REAL NVVR,NRR,NVRR,NV,NR,NPHI,NVPHI,NRPHI,MY,MX
        REAL JZZ,JXX,IPP,IXX,IZZ,LAMDA,N1,NSUM,NPROP
C
        INTEGER VLOW,CTYPE,CSTERN,ENGTYP
C
        CHARACTER MESSGE(9)*80
C
C
C COMMON BLOCKS OF DATA
C
C
        COMMON /CONST/ RHO,GRAV,PI,KVIS
        COMMON /SHIP/ TAFT,TFWD,LPP,LWL,B,CB,M,META,LCB,CWP,CMID,DEPTH
        COMMON /PROP/ PDIA,NBLADE,AEAO,PDRAT,XPROPR
        COMMON /RUDR/ HRUD,ARUD,XR,ZR
        COMMON /RESDAT/ ABULB,ATRANS,VLOW,SRUF,HB,CBTH,DBOW,CSTERN,CTYPE
C
C
C OPEN THE INPUT DATA FILE AND OUTPUT FILES
C
C
        OPEN (10,FILE='MNVRE.DAT',STATUS='OLD')
        OPEN (20,FILE='SIMUL.OUT',FORM='FORMATTED',STATUS='NEW')
C
C
C READ THE INPUT DATA FROM 'MNVRE.DAT'
C
C
        READ (10,*) RHO,KVIS,IAPP,DEPTH,THRAFT
     &             ,LPP,LWL,B,TAFT,TFWD,CB,CMID,CWP,M,META,LCB,KZZ,KXX
     &             ,VX1,VY1,R1,ETA1,N1,PSI1,PHI1,X1,Y1,S1,WFRAC,TFRAC
     &             ,XR,HRUD,WRO,ARUD,ZR,LAMDA,ZH,XMID,RUDRATE
     &             ,ITR,SRUF,ATRANS,CSTERN,CTYPE,CBTH,DBOW,ABULB,HB,NAPP
        IF (IAPP.NE.0) THEN
            READ (10,*) (ARAPP(I),K2(I),I=1,NAPP)
        END IF
        READ (10,*) MNVRE,TLIM,STEP,ORDANG,VLOW
     &             ,PDIA,PDRAT,AEAO,NBLADE,SHP,ENGTYP,XPROPR
     &             ,TDES,VCRSH,NRUDR,NSTERN,ASUB,NPROP,ISHIP,DELTANG
C
C
C WRITE INPUT DATA TO THE TIME SIMULATION OUTPUT FILE
C
C
        WRITE(20,700)
        IF (MNVRE.EQ.1) THEN
            WRITE(20,701)
          ELSE IF (MNVRE.EQ.2) THEN
            WRITE(20,702)
          ELSE
            WRITE(20,703)
        END IF
```

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      WRITE(20,704)
      WRITE(20,705)
      WRITE(20,706)
      WRITE(20,707) LPP
      WRITE(20,708) LWL
      WRITE(20,709) B
      WRITE(20,710) TAFT
      WRITE(20,711) TFWD
      WRITE(20,713) M/1000.
      WRITE(20,714) CB
      WRITE(20,715) CMID
      WRITE(20,716) CWP
      WRITE(20,719) ARUD
      WRITE(20,721) PDIA
      WRITE(20,722) PDRAT
      WRITE(20,723) AEAO
      WRITE(20,725) SHP/1000.
      WRITE(20,704)
C
C
C INITIALIZE ARRAY 'Y'
C
C
      Y(1)=VX1
      Y(2)=X1
      Y(3)=VY1
      Y(4)=Y1
      Y(5)=R1
      Y(6)=PSI1
      Y(7)=ETA1
      Y(8)=PHI1
      Y(9)=N1
      Y(10)=S1
C
C
C INITIALIZE REMAINING VARIABLES
C
      WIDTH1=0.
      IF (RUDRATE .EQ. 0.) THEN
          RUDRATE=2.5
      END IF
      TIME=0.
      ITIME=0
      GRAV=9.80665
      PI=3.141593
      NUM=10
      IGP=0
      IFLAG=0
      IC=0
      ANGOUT=0.
      INDEX=0
      K=0
      PERIOD1=0.
      PERIOD2=0.
      ISPIR=0
      END=0.
      COUNT=0.
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        TIMEFL=0.
        ZIGZAG=0.
        ANGMAX=ORDANG
        IF (MNVRE .EQ. 3) THEN
           IF (ORDANG .LT. 0.) THEN
              SPIRAL=-1.
           ELSE
              SPIRAL=1.
           END IF
        END IF
        DO 98 I=1,9
           IERROR(I)=0
   98 CONTINUE
C
C INITIALIZE CHARACTER VARIABLES
C
        IF (NPROP .EQ. 1.) THEN
C
C
C MESSAGES FOR SINGLE SCREW SHIPS
C
C

            MESSGE(1)='LENGTH BETWEEN PERPENDICULARS IS OUTSIDE THE
     &RANGE OF (55 <= LPP <= 330)'
            MESSGE(2)='BLOCK COEFFICIENT IS OUTSIDE THE RANGE OF.
     &(.56 <= CB <= .87)'
            MESSGE(3)='RUDDER ANGLE IS OUTSIDE THE RANGE OF
     &(+-10. <= ORDANG <= +-45.)'
            MESSGE(4)='RATIO (B/LPP) IS OUTSIDE THE RANGE OF
     &(.11 <= RATIO <= .18)'
            MESSGE(5)='RATIO (TAU/LPP) IS OUTSIDE THE RANGE OF
     &(0. <= RATIO <= .05)'
            MESSGE(6)='RATIO ((HRUD**2./LAMDA)/(LPP*T)) IS OUTSIDE
     &THE RANGE OF (.01 <= RATIO <= .04)'
            MESSGE(7)='RATIO (ASUB/(LPP*T)) IS OUTSIDE THE RANGE OF
     &(-.11 <= RATIO <= .04)'
            MESSGE(8)='RATIO (VX1/SQRT(LPP)) IS OUTSIDE THE RANGE OF
     &(.2 <= RATIO <= 1.0)'
            MESSGE(9)='RATIO (T/TDES) IS OUTSIDE THE RANGE OF
     &(.5 <= RATIO <= 1.0)'
        ELSE
C
C
C MESSAGES FOR TWIN SCREW SHIPS
C
C

            MESSGE(1)='LENGTH BETWEEN PERPENDICULARS IS OUTSIDE THE
     &RANGE OF (75 <= LPP <= 225)'
            MESSGE(2)='BLOCK COEFFICIENT IS OUTSIDE THE RANGE OF
     &(.42 <= CB <= .62)'
            MESSGE(3)='RUDDER ANGLE IS OUTSIDE THE RANGE OF
     &(+-10. <= ORDANG <= +-35.)'
            MESSGE(4)='RATIO (B/LPP) IS OUTSIDE THE RANGE OF
     &(.06 <= RATIO <= .2)'
            MESSGE(5)='RATIO (TAU/LPP) IS OUTSIDE THE RANGE OF
     &(-0.01 <= RATIO <= .03)'
            MESSGE(6)='RATIO ((HRUD**2./LAMDA)/(LPP*T)) IS OUTSIDE
     &THE RANGE OF (.01 <= RATIO <= .02)'
        MESSGE(7)='RATIO (ASUB/(LPP*T)) IS OUTSIDE THE RANGE OF
     &(-.1 <= RATIO <= 0.0)'
        MESSGE(8)='RATIO (VX1/SQRT(LPP)) IS OUTSIDE THE RANGE OF
     &(.25 <= RATIO <= 2.2)'
        MESSGE(9)='RATIO (T/TDES) IS OUTSIDE THE RANGE OF
     &(.6 <= RATIO <= 1.1)'
      END IF
C
C
C ALL VARIABLES HAVE BEEN INITIALIZED.
C THIS IS THE START OF THE TIME SIMULATION.
C
C
C
C CALL SUBROUTINE 'CONSTN' TO CALCULATE VARIABLES USING INPUT DATA
C
        CALL CONSTN(KXX,KZZ,ISHIP,IXX,IZZ,T,MY,MX,JZZ,JXX,AH,OM,DAMP,
     &              SPRING,IPP,TAU)
C
C
C CALL SUBROUTINE 'RESIST' TO CALCULATE THE SHIP RESISTANCE OVER
C A PARTICULAR SPEED RANGE.
C
        CALL RESIST(VX1,T,ITR,K2,NAPP,IAPP,ARAPP,RWAVE,RAPP,RBULB,RTRAN,
     &              RCOR,RFRIC,RTOT,SPD,CFORM,EHP,WFRAC,TFRAC)
C
C
C WRITE OUTPUT FROM 'RESIST' TO OUTPUT FILE 'SIMUL.OUT'
C
C
        WRITE(20,760)
        WRITE(20,761)
        WRITE(20,762)
        WRITE(20,763)
        WRITE(20,704)
        DO 37 I=1,ITR
          WRITE(20,764)SPD(I)/.51444,RWAVE(I)/1000.,RAPP(I)/1000.
     &,RBULB(I)/1000.,RTRAN(I./1000.,RCOR(I)/1000.
     &,RFRIC(I)/1000.,RTOT(I)/1000.,EHP(I)
   37 CONTINUE
        WRITE(20,765) WFRAC
        WRITE(20,766) TFRAC
        WRITE(20,767) CFORM
        WRITE(20,*)
        WRITE(20,*) ' The friction resistance in the above table was'
        WRITE(20,*) ' multiplied by (1.+CFORM) to obtain the total'
        WRITE(20,*) ' resistance.'
        WRITE(20,704)
C
C
C WRITE HEADING FOR OUTPUT TABLE OF SIMULATION RESULTS
C
C
        WRITE(20,727)
      WRITE(20,728)
      WRITE(20,729)
      WRITE(20,704)
C
C
C WRITE THE INITIAL VALUES OF THE SIMULATION
C
C
            WRITE (20,730)TIME,Y(1)/.51444,Y(3)/.51444,
     &(SQRT(Y(1)**2.+Y(3)**2.))/.51444,Y(2),Y(4),Y(6)*180./PI,
     &Y(8)*180./PI,Y(9)*60.
C
C
C CALL SUBROUTINE 'INTERP' TO CALCULATE THE VALUE OF SHIP RESISTANCE
C AT THE INITIAL MANOEUVRING SPEED.
C
C
      CALL INTERP(SPD,RTOT,VX1,ITR,XRES)
C
C
C CALL SUBROUTINE 'HYDER' TO CALCULATE THE HYDRODYNAMIC DERIVATIVES
C
C
      CALL HYDER(T,TAU,YV,YR,YVR,YVV,YRR,NVVR,NRR,NVRR,NV,NR,NPHI
     &          ,NVPHI,NRPHI)
C
C
C CALL SUBROUTINE 'JKTKQ' TO CALCULATE THE PROPELLER CHARACTERISTICS
C AT ANY TIME DURING THE MANOEUVRE.  THIS IS THE FIRST STEP IN THE
C PROCESS OF SOLVING THE DIFFERENTIAL EQUATIONS OF MOTION.
C
C
    8 CALL JKTKQ(WFRAC,Y,KT,KQ,JADV,WP)
C
C
C CALL SUBROUTINE 'RUDANG' TO CALCULATE THE INSTANTANEOUS RUDDER ANGLE
C
C
      CALL RUDANG(ITIME,TIME,TIMEFL,MNVRE,COUNT,SPIRAL,ZIGZAG,ANGMAX,
     &     DELTANG,ISPIR,Y,YWRATE,YAWANG,ORDANG,RUDRATE,STEP,RANGLE,
     &     RESSPIR,END,WIDTH1)
C
C
C CALL SUBROUTINE 'TEST' TO CALCULATE THE STANDARD MEASUREMENTS FOR
C EACH MANOEUVRE.
C
C
      CALL TEST(MNVRE,ITIME,TIME,Y,YAWANG,ANGMAX,ZIGZAG,X1,Y1,
     &          WIDTH1,PERIOD1,PERIOD2,RESULTS)
C
C
C CHECK TO DETERMINE IF THE MANOEUVRE HAS FINISHED
C
C
      IF (END .EQ. 1.) GO TO 7
C
C
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C
C CALL SUBROUTINE 'RUDFOR' TO CALCULATE THE INSTANTANEOUS RUDDER FORCE
C
      CALL RUDFOR(RANGLE,LAMDA,WFRAC,WRO,Y,WP,NPROP,FRN)
C
C
C CHECK TO SEE IF TIME LIMIT HAS BEEN EXCEEDED
C
C
      IF (TIME-TLIM)6,6,7
C
C
C CALL SUBROUTINE 'RUNGE' TO SOLVE THE DIFFERENTIAL EQUATIONS OF MOTION
C
C
    6 CALL RUNGE(NUM,Y,F,TIME,STEP,INDEX,K)
C
C
C BRANCH TO APPROPRIATE PORTION OF PROGRAM DEPENDING ON VALUE OF 'K'
C
C
      GO TO(10,20)K
C
C
C CALL SUBROUTINES 'XTERMS', 'YTERMS', 'YAWTM', 'ROLL', AND 'PROPR'
C TO CALCULATE THE VALUES OF THE DERIVATIVES OF THE INDEPENDENT
C VARIABLES, AT ANY TIME 'T'.
C
C
   10 CALL XTERMS(MY,Y,XRES,KT,TFRAC,FRN,RANGLE,VX1,MX,NPROP,XSUM)
C
      CALL YTERMS(MY,T,Y,MX,FRN,AH,RANGLE,YV,YR,YVR,YVV,YRR,YSUM,
     &            YTERM2,YTERM3)
C
      CALL YAWTM(T,Y,YTERM2,YTERM3,XMID,NVPHI,NRPHI,NPHI,NV,NR,
     &           NVVR,NVRR,NRR,AH,FRN,RANGLE,IZZ,JZZ,NSUM)
C
      CALL ROLL(SPRING,DAMP,Y,F,YTERM2,YTERM3,ZH,AH,IXX,JXX,
     &          RANGLE,FRN,RSUM)
C
      CALL PROPR(IPP,Y,KG,SHP,IGP,ENGTYP,PRPSUM)
C
C
C CALCULATE VALUES FOR DERIVATIVES OF INDEPENDENT VARIABLES
C
C
      F(1)=XSUM
      F(2)=Y(1)*COS(Y(6))-Y(3)*SIN(Y(6))
      F(3)=YSUM
      F(4)=Y(1)*SIN(Y(6))+Y(3)*COS(Y(6))
      F(5)=NSUM
      F(6)=Y(5)
      F(7)=RSUM
      F(8)=Y(7)
      F(9)=PRPSUM
      F(10)=Y(9)
C
```

```
      GO TO 6
C
C
C STORE VALUES OF YAW RATE AND YAW ANGLE
C
C
   20 ITIME=ITIME+1
      YWRATE(ITIME)=Y(5)
      YAWANG(ITIME)=Y(6)
C
C
C WRITE OUTPUT TO 'SIMUL.OUT'
C
C
      IPRNT=IPRNT+1
      IF (IPRNT .EQ. 10) THEN
         WRITE (20,730)TIME,Y(1)/.51444,Y(3)/.51444,
     &(SQRT(Y(1)**2.+Y(3)**2.))/.51444,Y(2),Y(4),Y(6)*180./PI,
     &Y(8)*180./PI,Y(9)*60.
         IPRNT=0
      END IF
      GO TO 8
    7 CONTINUE
C
C
C WRITE FINAL RESULTS TO THE OUTPUT FILE
C
C
      WRITE(20,*)
      WRITE(20,*)
      WRITE(20,731)
      IF (MNVRE .EQ. 1) THEN
          WRITE(20,701)
        ELSE IF (MNVRE .EQ. 2) THEN
          WRITE(20,702)
        ELSE
          WRITE(20,703)
      END IF
      WRITE(20,704)
      WRITE(20,705)
      WRITE(20,706)
      IF (MNVRE .EQ. 1) THEN
          WRITE(20,732) RESULTS(5)/.51444
          WRITE(20,733) ABS(RESULTS(1)/LPP)
          WRITE(20,734) ABS(RESULTS(2)/LPP)
          WRITE(20,735) ABS(RESULTS(3)/LPP)
          WRITE(20,736) ABS(RESULTS(4)/LPP)
        ELSE IF (MNVRE .EQ. 2) THEN
          WRITE(20,737) ABS(RESULTS(1)*180./PI)
          WRITE(20,738) ABS(RESULTS(2)/LPP)
          WRITE(20,739) RESULTS(3)
          WRITE(20,740) RESULTS(4)/LPP
        ELSE
          WRITE(20,741)
          WRITE(20,742)
          WRITE(20,743)
          WRITE(20,744) ANGMAX
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```
                WRITE(20,745) DELTANO
                DO 99 I=1,ISPIR
                  IF (ANGMAX .GT. 0.) THEN
                     ANGOUT=ANGMAX-((I-1)*DELTANO)
                     IF (ANGOUT .GE. -ANGMAX) THEN
                        WRITE(20,781) ANGOUT
                     ELSE
                        IC=IC+1
                        WRITE (20,781) -ANGMAX+(DELTANO*IC)
                     END IF
                  ELSE
                     ANGOUT=ANGMAX+((I-1)*DELTANO)
                     IF (ANGOUT .LE. -ANGMAX) THEN
                        WRITE(20,781) ANGOUT
                     ELSE
                        IC=IC+1
                        WRITE(20,781) -ANGMAX-(DELTANO*IC)
                     END IF
                  END IF
                  WRITE(20,746) RESSPIR(I)*180./PI
      99        CONTINUE
            END IF
            WRITE(20,704)
C
C
C     CALCULATE THE EMPIRICAL ESTIMATES
C
C     WRITE THE HEADER FOR THE OUTPUT TABLE
C
C

            WRITE(20,*)
            WRITE(20,*)
            WRITE(20,747)
C
C
C     CALL SUBROUTINE 'CIRCLE' TO OBTAIN AN EMPIRICAL ESTIMATE OF THE
C     TURNING CIRCLE CHARACTERISTICS.
C

            IF (MNVRE .EQ. 1) THEN
                  CALL CIRCLE(TAU,ORDANG,ASUB,LAMDA,VX1,NPROP,NSTERN,NRUDR,
     &                        TDES,T,VST,ADV,TR,TACDIA,STDYDIA,IERROR)
C
C
C     WRITE THE RESULTS OF THE EMPIRICAL ANALYSIS
C
C

                  WRITE(20,701)
                  WRITE(20,704)
                  WRITE(20,705)
                  WRITE(20,706)
                  WRITE(20,732) VST
                  WRITE(20,733) ABS(ADV/LPP)
                  WRITE(20,734) ABS(TR/LPP)
                  WRITE(20,735) ABS(TACDIA/LPP)
                  WRITE(20,736) ABS(STDYDIA/LPP)
                  IF (NPROP .EQ. 1.) THEN
                WRITE(20,771)
                WRITE(20,772)
                WRITE(20,773)
                WRITE(20,774)
                WRITE(20,775)
             ELSE
                WRITE(20,776)
                WRITE(20,777)
                WRITE(20,778)
                WRITE(20,779)
                WRITE(20,780)
          END IF
          WRITE(20,*)
          WRITE(20,*)
          WRITE(20,768)
          WRITE(20,769)
          DO 88 I=1,9
             IF (IERROR(I) .EQ. 1) THEN
                WRITE(20,748) MESSGE(I)
                IFLAG=1
             END IF
 88       CONTINUE
          IF (IFLAG .EQ. 0) THEN
             WRITE(20,*)
             WRITE(20,770)
          END IF
          WRITE(20,704)
       END IF
C
C
C CALL SUBROUTINE 'CRASH'
C
C
       CALL CRASH(VCRSH,XRES,M,THRAFT,SPD,RTOT,ITR,REACH)
C
C
C WRITE RESULTS TO THE OUTPUT FILE
C
C
       WRITE(20,*)
       WRITE(20,*)
       WRITE(20,749)
       WRITE(20,704)
       WRITE(20,705)
       WRITE(20,706)
       WRITE(20,750) VCRSH/.51444
       WRITE(20,751) XRES/1000.
       WRITE(20,752) THRAFT/1000.
       WRITE(20,753) REACH/LPP
       WRITE(20,704)

C
C
C CLOSE ALL FILES
C
C
       CLOSE(10)
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```
        CLOSE(20)
C
C
C FORMAT STATEMENTS
C
C
 700 FORMAT(52X,'INPUT DATA')
 701 FORMAT('0',45X,'TURNING CIRCLE MANDEUVRE')
 702 FORMAT('0',49X,'ZIGZAG MANDEUVRE')
 703 FORMAT('0',49X,'SPIRAL MANDEUVRE')
 704 FORMAT('0',1X,'********************************************************
    &*********************************************************')
 705 FORMAT('0',25X,'DESCRIPTION',36X,'VALUE',25X,'UNITS')
 706 FORMAT(1X,'________________________________________________________
    &_________________________________________________________')
 707 FORMAT('0',1X,'LENGTH BETWEEN PERPENDICULARS',42X,F6.2,23X,
    &'METERS')
 708 FORMAT('0',1X,'LENGTH ON WATERLINE',52X,F6.2,23X,'METERS')
 709 FORMAT('0',1X,'BREADTH',65X,F5.2,23X,'METERS')
 710 FORMAT('0',1X,'DRAFT AFT',63X,F5.2,23X,'METERS')
 711 FORMAT('0',1X,'DRAFT FWD',63X,F5.2,23X,'METERS')
 713 FORMAT('0',1X,'DISPLACEMENT',56X,F9.2,23X,'TONNES')
 714 FORMAT('0',1X,'BLOCK COEFFICIENT',56X,F4.2,24X,'-----')
 715 FORMAT('0',1X,'MIDSHIP SECTION COEFFICIENT',46X,F4.2,24X,'-----')
 716 FORMAT('0',1X,'WATERPLANE COEFFICIENT',51X,F4.2,24X,'-----')
 719 FORMAT('0',1X,'RUDDER LATERAL AREA',52X,F5.1,24X,'SQ. METERS')
 721 FORMAT('0',1X,'PROPELLER DIAMETER',54X,F5.2,23X,'METERS')
 722 FORMAT('0',1X,'PROPELLER PITCH/DIAMETER RATIO',43X,F4.2,
    &24X,'-----')
 723 FORMAT('0',1X,'PROPELLER EXPANDED BLADE AREA RATIO',38X,F4.2,
    &24X,'-----')
 725 FORMAT('0',1X,'SHAFT HORSEPOWER',52X,F8.1,27X,'KW')
 727 FORMAT('0',3X,'TIME',6X,'LOCAL',6X,'LOCAL',7X,'LOCAL',9X,'GLOBAL',
    &8X,'GLOBAL',6X,'YAW ANGLE',4X,'ROLL ANGLE',4X,'PROPELLER')
 728 FORMAT(12X,'X-SPEED',4X,'Y-SPEED',4X,'SHIP SPEED',4X,'X-POSITION',
    &4X,'Y-POSITION',33X,'SPEED')
 729 FORMAT(3X,'(SECS)',4X,'(KNOTS)',4X,'(KNOTS)',5X,'(KNOTS)',7X,
    &'(METERS)',6X,'(METERS)',5X,'(DEGREES)',4X,'(DEGREES)',7X,'(RPM)')
 730 FORMAT('0',2X,F6.1,5X,F5.2,5X,F6.2,7X,F5.2,7X,F9.2,5X,F9.2,
    &6X,F6.1,8X,F5.1,8X,F6.1)
 731 FORMAT(41X,'RESULTS FROM TIME SIMULATION ANALYSIS')
 732 FORMAT('0',1X,'STEADY TURNING SPEED',50X,F5.2,26X,'KNOTS')
 733 FORMAT('0',1X,'NON-DIMENSIONAL ADVANCE (ADVANCE/LPP)',34X,F4.2,
    &26X,'-----')
 734 FORMAT('0',1X,'NON-DIMENSIONAL TRANSFER (TRANSFER/LPP)',32X,F4.2,
    &26X,'-----')
 735 FORMAT('0',1X,'NON-DIMENSIONAL TACTICAL DIAMETER (TAC. DIA./LPP)',
    &22X,F4.2,26X,'-----')
 736 FORMAT('0',1X,'NON-DIMENSIONAL STEADY TURNING DIAMETER (STDY.
    &DIA./LPP)',15X,F4.2,26X,'-----')
 737 FORMAT('0',1X,'OVERSHOOT ANGLE',56X,F5.2,24X,'DEGREES')
 738 FORMAT('0',1X,'NON-DIMENSIONAL OVERSHOOT WIDTH OF PATH (WIDTH
    &/LPP)',21X,F4.2,25X,'-----')
 739 FORMAT('0',1X,'PERIOD BETWEEN 1st RUDDER CHANGE AND 3rd RUDDER
    &CHANGE',16X,F5.1,26X,'SECS.')
 740 FORMAT('0',1X,'NON-DIMENSIONAL REACH (REACH/LPP)',39X,F4.2,25X,
    &'-----')
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  741 FORMAT('0',1X,'THE RESULTS FOR THE SPIRAL TEST ARE SUMMARIZED
     &BELOW.  THEY ARE THE')
  742 FORMAT('0',1X,'CONSTANT RATES OF TURN AT EACH RUDDER ANGLE,
     &STARTING WITH THE INITIAL')
  743 FORMAT('0',1X,'ANGLE, AND SUBSEQUENTLY CHANGING BY "DELTANG".')
  744 FORMAT('0',1X,'THE INITIAL RUDDER ANGLE IS',44X,F6.2,23X,
     &'DEGREES')
  745 FORMAT('0',1X,'THE CHANGE OF RUDDER ANGLE IS',44X,F4.2,23X,
     &'DEGREES')
  746 FORMAT(1X,'THE CONSTANT YAW RATE IS',46X,E10.3,21X,
     &'DEG./SEC.')
  747 FORMAT('0',44X,'RESULTS FROM THE EMPIRICAL ANALYSIS')
  748 FORMAT('0',1X,A)
  749 FORMAT('0',50X,'CRASH STOP MANOEUVRE')
  750 FORMAT('0',1X,'INITIAL SPEED OF SHIP',50X,F5.2,25X,'KNOTS')
  751 FORMAT('0',1X,'INITIAL RESISTANCE OF SHIP',43X,F6.1,27X,'KN')
  752 FORMAT('0',1X,'MAXIMUM ASTERN THRUST',47X,F7.1,27X,'KN')
  753 FORMAT('0',1X,'NON-DIMENSIONAL HEAD REACH (REACH/LPP)',
     &33X,F5.2,25X,'-----')
  760 FORMAT('0',37X,'SHIP SPEED - POWER DATA')
  761 FORMAT('0',2X,'SPEED',5X,'WAVE',7X,'APPEND',5X,'BULB BOW',4X,
     &'TRANSOM',6X,'CORR.',6X,'FRICTION',5X,'TOTAL',6X,'EFFECTIVE')
  762 FORMAT(12X,'RESIST',6X,'RESIST',6X,'RESIST',6X,'RESIST',5X,
     &'RESIST',7X,'RESIST',6X,'RESIST',5X,'HORSEPOWER')
  763 FORMAT(2X,'(KNOTS)',4X,'(KN)',8X,'(KN)',8X,'(KN)',8X,'(KN)',
     &8X,'(KN)',8X,'(KN)',9X,'(KW)')
  764 FORMAT('0',2X,F4.1,3X,7(E10.3,2X),1X,E10.3)
  765 FORMAT('0',1X,'WAKE FRACTION = ',1X,F5.3)
  766 FORMAT('0',1X,'THRUST DEDUCTION FRACTION = ',1X,F5.3)
  767 FORMAT('0',1X,'FORM FACTOR OF THE HULL = ',1X,F5.3)
  768 FORMAT(1X,'MESSAGES FOR EMPIRICAL TURNING CIRCLE ANALYSIS')
  769 FORMAT(1X,'______________________________________________')
  770 FORMAT(1X,'ALL PARAMETERS ARE WITHIN THE ALLOWABLE LIMITS')
  771 FORMAT('0',1X,'STANDARD DEVIATION OF (VST/VX1) = 0.185')
  772 FORMAT('0',1X,'STANDARD DEVIATION OF (ADV/LPP) = 0.162')
  773 FORMAT('0',1X,'STANDARD DEVIATION OF (TR/LPP) = 0.170')
  774 FORMAT('0',1X,'STANDARD DEVIATION OF (TACDIA/LPP) = 0.111')
  775 FORMAT('0',1X,'STANDARD DEVIATION OF (STDYDIA/LPP) = 0.244')
  776 FORMAT('0',1X,'STANDARD DEVIATION OF (VST/VX1) = 0.166')
  777 FORMAT('0',1X,'STANDARD DEVIATION OF (ADV/LPP) = 0.188')
  778 FORMAT('0',1X,'STANDARD DEVIATION OF (TR/LPP) = 0.129')
  779 FORMAT('0',1X,'STANDARD DEVIATION OF (TACDIA/LPP) = 0.066')
  780 FORMAT('0',1X,'STANDARD DEVIATION OF (STDYDIA/LPP) = 0.271')
  781 FORMAT('0',2X,'THE ANGLE IS = ',F5.1)
C
C
C END OF MAIN PROGRAM
C
C
      STOP
      END
```

```
PROGRAM SECTIONS

    Name                                 Bytes   Attributes

  0 $CODE                                 5615   PIC CON REL LCL   SHR   EXE   RD NOWRT LONG
  1 $PDATA                                4885   PIC CON REL LCL   SHR NOEXE   RD NOWRT LONG
  2 $LOCAL                               35512   PIC CON REL LCL NOSHR NOEXE   RD   WRT LONG
  3 CONST                                   16   PIC OVR REL GBL   SHR NOEXE   RD   WRT LONG
  4 SHIP                                    48   PIC OVR REL GBL   SHR NOEXE   RD   WRT LONG
  5 PROP                                    20   PIC OVR REL GBL   SHR NOEXE   RD   WRT LONG
  6 RUDR                                    16   PIC OVR REL GBL   SHR NOEXE   RD   WRT LONG
  7 RESDAT                                  36   PIC OVR REL GBL   SHR NOEXE   RD   WRT LONG

    Total Space Allocated                46148

ENTRY POINTS

    Address   Type  Name

  0-00000000        MANOEUVRE

VARIABLES

    Address   Type  Name              Address   Type  Name              Address   Type  Name              Address   Type  Name

  7-00000000  R*4  ABULB            2-000086D8  R*4  ADV              5-00000008  R*4  AEAD             2-0000867C  R*4  AH
  2-00008670  R*4  ANGMAX               **      R*4  ANGOUT           6-00000004  R*4  ARUD             2-0000862C  R*4  ASUB
  7-00000004  R*4  ATRANS           4-00000010  R*4  B                4-00000014  R*4  CB               7-00000014  R*4  CBTH
  2-00008690  R*4  CFORM            4-00000028  R*4  CMID             2-00008664  R*4  COUNT            7-0000001C  I*4  CSTERN
  7-00000020  I*4  CTYPE            4-00000024  R*4  CWP              2-00008684  R*4  DAMP             7-00000018  R*4  DBOW
  2-00008634  R*4  DELTANG          4-0000002C  R*4  DEPTH            2-00008660  R*4  END              2-000085B8  I*4  ENGTYP
  2-000085D0  R*4  ETA1             2-000086B4  R*4  FRN              2-00008680  R*4  GM               3-00000004  R*4  GRAV
  7-00000010  R*4  HB               6-00000000  R*4  HRUD                 **      I*4  I                2-000085BC  I*4  IAPP
      **      I*4  IC                   **      I*4  IFLAG            2-0000864C  I*4  INDEX            2-0000859C  R*4  IPP
  2-000086D0  I*4  IPRNT            2-00008648  I*4  IGP              2-00008630  I*4  ISHIP            2-0000865C  I*4  ISPIR
  2-00008640  I*4  ITIME            2-00008600  I*4  ITR              2-000085A0  R*4  IXX              2-000085A4  R*4  IZZ
  2-00008568  R*4  JADV             2-00008598  R*4  JXX              2-00008594  R*4  JZZ              2-00008650  I*4  K
  2-00008564  R*4  KG               2-00008560  R*4  KT               3-0000000C  R*4  KVIS             2-00008558  R*4  KXX
  2-0000855C  R*4  KZZ              2-000085A8  R*4  LAMDA            4-00000020  R*4  LCB              4-00000008  R*4  LPP
  4-0000000C  R*4  LWL              4-00000018  R*4  M                4-0000001C  R*4  META             2-00008608  I*4  MNVRE
  2-00008590  R*4  MX               2-0000858C  R*4  MY               2-000085AC  R*4  N1               2-00008604  I*4  NAPP
  5-00000004  I*4  NBLADE           2-00008580  R*4  NPHI             2-000085B4  R*4  NPROP            2-0000857C  R*4  NR
  2-00008588  R*4  NRPHI            2-00008570  R*4  NRR              2-00008624  I*4  NRUDR            2-00008628  I*4  NSTERN
  2-000085B0  R*4  NSUM             2-00008644  I*4  NUM              2-00008578  R*4  NV               2-00008584  R*4  NVPHI
  2-00008574  R*4  NVRR             2-0000856C  R*4  NVVR             2-00008614  R*4  ORDANG           5-00000000  R*4  PDIA
  5-0000000C  R*4  PDRAT            2-00008654  R*4  PERIOD1          2-00008658  R*4  PERIOD2          2-000085D8  R*4  PHI1
  3-00000008  R*4  PI               2-000086CC  R*4  PRPSUM           2-000085D4  R*4  PSI1             2-000085CC  R*4  R1
  2-000086B0  R*4  RANGLE           2-000086E8  R*4  REACH            3-00000000  R*4  RHO              2-000086C8  R*4  RSUM
  2-000085FC  R*4  RUDRATE          2-000085E4  R*4  S1               2-00008618  R*4  SHP              2-00008674  R*4  SPIRAL
  2-00008688  R*4  SPRING           7-0000000C  R*4  SRUF             2-000086E4  R*4  STDYDIA          2-00008610  R*4  STEP
  2-00008678  R*4  T                2-000086E0  R*4  TACDIA           4-00000000  R*4  TAFT             2-0000868C  R*4  TAU
  2-0000861C  R*4  TDES             2-000085EC  R*4  TFRAC            4-00000004  R*4  TFWD             2-000085C0  R*4  THRAFT
  2-0000863C  R*4  TIME             2-00008668  R*4  TIMEFL           2-0000860C  R*4  TLIM             2-000086DC  R*4  TR
  2-00008620  R*4  VCRSH            7-00000008  I*4  VLOW             2-000086D4  R*4  VST              2-000085C4  R*4  VX1
  2-000085C8  R*4  VY1              2-000085E8  R*4  WFRAC            2-00008638  R*4  WIDTH1           2-000086AC  R*4  WP
```

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   2-000085F0  R*4   WRO                 2-000085DC  R*4   X1                 2-000085F8  R*4   XMID                  5-00000010  R*4   XPROPR
   6-00000008  R*4   XR                  2-00008694  R*4   XRES               2-000086B8  R*4   XSUM                  2-000085E0  R*4   Y1
   2-0000869C  R*4   YR                  2-000086A8  R*4   YRR                2-000086BC  R*4   YSUM                  2-000086C0  R*4   YTERM2
   2-000086C4  R*4   YTERM3              2-00008698  R*4   YV                 2-000086A0  R*4   YVR                   2-000086A4  R*4   YVV
   2-000085F4  R*4   ZH                  2-0000866C  R*4   ZIGZAG             6-0000000C  R*4   ZR

ARRAYS

    Address    Type  Name                        Bytes  Dimensions

   2-000004B0  R*4   ARAPP
   2-00000438  R*4   EHP                            40  (10)
   2-00000028  R*4   F                             120  (30)
   2-00008200  I*4   IERROR                         40  (10)
   2-000004D8  R*4   K2                             36  (9)
   2-00008288  CHAR  MESSGE                         40  (10)
   2-00000050  R*4   Q                             720  (9)
   2-00000168  R*4   RAPP                           40  (10)
   2-000001E0  R*4   RBULB                         120  (30)
   2-000002D0  R*4   RCOR                          120  (30)
   2-00008238  R*4   RESSPIR                       120  (30)
   2-00008224  R*4   RESULTS                        80  (20)
   2-00000348  R*4   RFRIC                          20  (5)
   2-00000078  R*4   RTOT                          120  (30)
   2-00000258  R*4   RTRAN                         120  (30)
   2-000000F0  R*4   RWAVE                         120  (30)
   2-000003C0  R*4   SPD                           120  (30)
   2-00000000  R*4   Y                             120  (30)
   2-00000500  R*4   YAWANG                         40  (10)
   2-00004380  R*4   YWRATE                      16000  (4000)
                                                 16000  (4000)

LABELS

    Address    Label        Address    Label        Address    Label        Address    Label        Address    Label        Address    Label

      **       6         0-00000D50    7         0-00000B48    8         0-00000B9B    10        0-00000C54    20             **       37
      **       88            **        98            **        99        1-0000007C    700'      1-000000BB    701'      1-000000AB    702'
   1-000000C3  703'      1-000000DB    704'      1-00000154    705'      1-00000179    706'      1-000001F1    707'      1-00000225    708'
   1-0000024F  709'      1-0000026D    710'      1-0000028D    711'      1-000002AD    713'      1-000002D0    714'      1-000002F7    715'
   1-00000328  716'      1-00000354    719'      1-00000382    721'      1-000003AB    722'      1-000003DF    723'      1-00000418    725'
   1-0000043B  727'      1-0000049E    728'      1-000004EB    729'      1-0000054F    730'      1-000005B0    731'      1-000005AA    732'
   1-000005D4  733'      1-0000060F    734'      1-0000064C    735'      1-00000693    736'      1-000006E1    737'      1-00000708    738'
   1-00000751  739'      1-0000079D    740'      1-000007D4    741'      1-0000081F    742'      1-0000086D    743'      1-000008A3    744'
   1-000008D6  745'      1-0000090B    746'      1-0000093A    747'      1-00000965    748'      1-0000096C    749'      1-00000988    750'
   1-000009B3  751'      1-000009E0    752'      1-00000A08    753'      1-00000A44    760'      1-00000A63    761'      1-00000AC4    762'
   1-00000B19  763'      1-00000B65    764'      1-00000B7F    765'      1-00000B9C    766'      1-00000BC5    767'      1-00000BEC    768'
   1-00000C1F  769'      1-00000C52    770'      1-00000CB5    771'      1-00000CB4    772'      1-00000CE3    773'      1-00000D11    774'
   1-00000D43  775'      1-00000D76    776'      1-00000DA5    777'      1-00000DD4    778'      1-00000E02    779'      1-00000E34    780'
   1-00000E67  781'
```

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FUNCTIONS AND SUBROUTINES REFERENCED

  Type  Name                Type  Name                Type  Name                Type  Name                Type  Name                Type  Name

        CIRCLE                    CONSTN                    CRASH                     FOR$CLOSE                 FOR$OPEN                  HYDER
        INTERP                    JKTKG               R*4   MTH$COS             R*4   MTH$SIN             R*4   MTH$SQRT                  PROPR
        RESIST                    ROLL                      RUDANG                    RUDFOR                    RUNGE                     TEST
        XTERMS                    YAWTM                     YTERMS
```

```
C
C
C*******************************************************************************
C
C
C                            SUBROUTINE CONSTN
C
C
C*******************************************************************************
C
C
      SUBROUTINE CONSTN(KXX,KZZ,ISHIP,IXX,IZZ,T,MY,MX,JZZ,JXX,AH,GM,
     &      DAMP,SPRING,IPP,TAU)
C
C
C THIS SUBROUTINE CALCULATES CONSTANTS USING THE BASIC INPUT DATA.  THE
C CONSTANTS ARE USED THROUGHOUT THE PROGRAM.
C
C The input variables are:
C
C             1) KXX    - Transverse radius of gyration (meters).
C                         If this variable is initially equal to zero (0.)
C                         then the computer will estimate a value.
C
C             2) KZZ    - Yaw radius of gyration (meters).  If this variable
C                         is initially equal to zero (0.), then the
C                         computer will estimate a value.
C
C             3) ISHIP  - Indicates which empirical formula to use when
C                         calculating KXX and KZZ.
C
C The output variables are:
C
C             1) T      - Mean draft (meters)
C
C             2) MY     - Added mass of ship in y-direction (kg)
C
C             3) MX     - Added mass of ship in x-direction (kg)
C
C             4) JZZ    - Added yaw mass moment of inertia about the
C                         z-axis (kg-m**2)
C
C             5) JXX    - Added roll mass moment of inertia about the
C                         x-axis (kg-m**2)
C
C             6) AH     - Coefficient used in rudder force calculation
C
C             7) GM     - Metacentric height (meters)
C
C             8) DAMP   - Roll damping coefficient used in the roll equation
C                         of motion (kg-m**2/sec)
C
C             9) SPRING - Roll restoring moment coefficient (kg-m**2/sec)
C
C             10) IPP   - Virtual mass moment of inertia of the propeller,
C                         including the added mass (kg-m**2)
C
```

```
C                11) TAU   - Trim of ship (meters)
C
C COMMON BLOCKS OF DATA
C
C
      COMMON /CONST/ RHO,GRAV,PI,KVIS
      COMMON /SHIP/ TAFT,TFWD,LPP,LWL,B,CB,M,META,LCB,CWP,CMID,DEPTH
      COMMON /PROP/ PDIA,NBLADE,AEAO,PDRAT,XPROPR
C
C
C DECLARE REAL AND INTEGER VARIABLES
C
C
      REAL MY,MX,JZZ,JXX,IPP,KXX,KVIS,LPP,LWL,M,META,LCB
      REAL IXX,IZZ,KZZ
C
C
C CALCULATE CONSTANTS
C
C
      T = (TAFT+TFWD)/2.
C
      AH = 0.627*CB-0.153
C
      MY = 0.5*PI*RHO*LPP*(T**2.)
C
      IF (KXX .EQ. 0.) THEN
          IF (ISHIP .EQ. 0) THEN
             KXX=0.2939*SQRT(B**2.+DEPTH**2.)
            ELSE IF (ISHIP .EQ. 1) THEN
             KXX=0.3177*SQRT(B**2.+DEPTH**2.)
            ELSE IF (ISHIP .EQ. 2) THEN
             KXX=0.2979*SQRT(B**2.+DEPTH**2.)
            ELSE
             KXX=SQRT((B**2.*(CWP**2.)/(11.4*CB))+(DEPTH**2./12.))
          END IF
      END IF
      IXX=(KXX**2.)*M
C
      IF (KZZ .EQ. 0.) THEN
          IF (ISHIP .EQ. 0) THEN
             KZZ=0.2891*SQRT(LPP**2.+B**2.)
            ELSE IF (ISHIP .EQ. 1) THEN
             KZZ=0.2804*SQRT(LPP**2.+B**2.)
            ELSE IF (ISHIP .EQ. 2) THEN
             KZZ=0.2672*SQRT(LPP**2.+B**2.)
            ELSE
             KZZ=0.25*LPP
          END IF
      END IF
      IZZ=(KZZ**2.)*M
C
      MX = 0.55*RHO*LPP*(T**2.)
C
      JXX = 0.013*RHO*CB*LPP*(B**3.)*T*(1.+0.037*B/T)**2.
C
      JZZ = PI*RHO*(LPP**3.)*(T**2.)/24.
      C
              IF (META .NE. 0.) THEN
                 GM=META
                ELSE
                 GM = (-0.09+0.0965*CB+0.0548*B/T)*B
              END IF
      C
              DAMP = -0.214*KXX*M*SQRT(GRAV*GM)
      C
              SPRING = -M*GRAV*GM
      C
              IPP = 20.*PDIA**5.
      C
              TAU = TAFT-TFWD
      C
      C
      C RETURN TO MAIN PROGRAM
      C
      C
              RETURN
              END


PROGRAM SECTIONS

    Name                                  Bytes   Attributes

  0 $CODE                                   648   PIC CON REL LCL   SHR   EXE   RD NOWRT LONG
  3 CONST                                    16   PIC OVR REL GBL   SHR NOEXE   RD   WRT LONG
  4 SHIP                                     48   PIC OVR REL GBL   SHR NOEXE   RD   WRT LONG
  5 PROP                                     20   PIC OVR REL GBL   SHR NOEXE   RD   WRT LONG

    Total Space Allocated                   732

ENTRY POINTS

    Address   Type   Name

  0-00000000         CONSTN

VARIABLES

    Address   Type   Name               Address   Type   Name               Address   Type   Name               Address   Type   Name

  5-00000008  R*4   AEAO            AP-0000002C@ R*4   AH               4-00000010  R*4   B                4-00000014  R*4   CB
  4-00000028  R*4   CMID              4-00000024  R*4   CWP           AP-00000034@ R*4   DAMP             4-0000002C  R*4   DEPTH
AP-00000030@ R*4   GM                 3-00000004  R*4   GRAV          AP-0000003C@ R*4   IPP           AP-0000000C@ I*4   ISHIP
AP-00000010@ R*4   IXX             AP-00000014@ R*4   IZZ           AP-00000028@ R*4   JXX           AP-00000024@ R*4   JZZ
  3-0000000C  R*4   KVIS           AP-00000004@ R*4   KXX           AP-00000008@ R*4   KZZ              4-00000020  R*4   LCB
  4-00000008  R*4   LPP               4-0000000C  R*4   LWL              4-00000018  R*4   M                4-0000001C  R*4   META
AP-00000020@ R*4   MX              AP-0000001C@ R*4   MY               5-00000004  I*4   NBLADE           5-00000000  R*4   PDIA
  5-0000000C  R*4   PDRAT             3-00000008  R*4   PI               3-00000000  R*4   RHO           AP-00000038@ R*4   SPRING
AP-00000018@ R*4   T                  4-00000000  R*4   TAFT          AP-00000040@ R*4   TAU              4-00000004  R*4   TFWD
```

```
  5-00000010  R*4  XPROPR

FUNCTIONS AND SUBROUTINES REFERENCED

  Type  Name
   R*4  MTH$SQRT
```

```
C
C
C**********************************************************************
C
C
C                          SUBROUTINE RESIST
C
C
C**********************************************************************
C
C
      SUBROUTINE RESIST(VX1,T,ITR,K2,NAPP,IAPP,ARAPP,RWAVE,RAPP,RBULB,
     &          RTRAN,RCOR,RFRIC,RTOT,SPD,CFORM,EHP,WFRAC,TFRAC)
C
C
C THIS SUBROUTINE CALCULATES THE RESISTANCE OF THE SHIP AS A FUNCTION
C SHIP SPEED, ACCORDING TO 'HOLTROP AND MENNEN' (REFS. 14,15 MAIN REPORT).
C ARRAYS OF RESISTANCE AND SPEED WILL BE RETURNED TO THE MAIN PROGRAM.
C THESE VALUES WILL THEN BE USED IN AN INTERPOLATION SUBROUTINE TO
C DETERMINE THE SPECIFIC VALUE OF RESISTANCE AT THE INITIAL SPEED.
C
C DIMENSION VARIABLES
C
C
      DIMENSION K2(NAPP),ARAPP(NAPP),RTOT(ITR),RWAVE(ITR),RAPP(ITR)
      DIMENSION RBULB(ITR),RTRAN(ITR),RCOR(ITR),SPD(ITR),EHP(ITR)
      DIMENSION RFRIC(ITR)
C
C
C COMMON BLOCKS OF DATA
C
C
      COMMON /CONST/ RHO,GRAV,PI,KVIS
      COMMON /SHIP/ TAFT,TFWD,LPP,LWL,B,CB,M,META,LCB,CWP,CMID,DEPTH
      COMMON /PROP/ PDIA,NBLADE,AEAO,PDRAT,XPROPR
      COMMUN /RESDAT/ABULB,ATRANS,VLOW,SRUF,HB,CBTH,DBOW,CBTERN,CTYPE
C
C
C DECLARE REAL AND INTEGER VARIABLES
C
C
      REAL M3,LAMBDA,MONE,MTWO,MTHR,M1,M4,M44,M45,LRUN,K2EQ,K2
      REAL LPP,LWL,M,META,LCB,KVIS
      INTEGER VLOW,CSTERN,CTYPE
C
C
C INPUT VARIABLES ARE:
C
C          1) VX1      - Initial ship speed at the start of the
C                        manoeuvre (m/sec).
C
C          2) T        - Mean draft of the ship (meters).
C
C          3) ITR      - Total number of speeds for which a value
C                        of resistance is to be calculated.
C
C          4) K2       - Vector containing the coefficients for each
```

```
C                                 of the appendages fitted to the ship. (Refer
C                                 to the User Manual for a complete description).
C
C                5) NAPP        - The number of appendages fitted to the ship.
C
C                6) IAPP        - Indicates if the resistance estimate is for a
C                                 bare hull, or hull with appendages.
C
C                7) ARAPP       - Vector containing the areas of the appendages
C                                 fitted to the ship (m**2).
C
C OUTPUT VARIABLES ARE:
C
C                1) RWAVE       - Wave resistance vector (Newtons).
C
C                2) RAPP        - Appendage resistance vector (Newtons).
C
C                3) RBULB       - Vector containing values of resistance due to
C                                 the bulbous bow (Newtons).
C
C                4) RTRAN       - Vector containing values of resistance due to
C                                 the immersed transom area (Newtons).
C
C                5) RCOR        - Vector containing values of correlation resistance
C                                 (Newtons).
C
C                6) RFRIC       - Friction resistance vector, calculated according to
C                                 the 1957 I.T.T.C. Line (Newtons).
C
C                7) RTOT        - Total resistance vector (Newtons).
C
C                8) SPD         - Vector containing values of ship speed for each
C                                 value of resistance (m/sec.).
C
C                9) CFORM       - Form factor for the hull.
C
C               10) EHP         - Effective horsepower vector (kilowatts).
C
C               11) WFRAC       - Wake fraction.
C
C               12) TFRAC       - Thrust deduction fraction.
C
C INITIALIZE VARIABLES IN THE ARGUMENT LIST
C
C
        DO 11 I = 1,ITR
           SPD(I)=0.
           RTOT(I)=0.
   11   CONTINUE
C
C
C CALCULATE COEFFICIENTS FOR FORM FACTOR 'CFORM'
C
C
        CPRIS = CB/CMID
        LRUN = LWL*(1.-CPRIS+0.06*CPRIS*LCB/(4.*CPRIS-1.))
        C14 = 1.+0.011*CSTERN
```

```
C
C
C TERMS USED TO CALCULATE FORM FACTOR 'CFORM'
C
C
      FORM1 = 0.487118*C14*(B/LWL)**1.06806
      FORM2 = (T/LWL)**0.46106
      FORM3 = (LWL/LRUN)**0.121563
      FORM4 = (LWL**3./(M/RHO))**0.36486
      FORM5 = (1.-CPRIS)**-0.604247
      CFORM = (0.93+FORM1*FORM2*FORM3*FORM4*FORM5)-1.
C
C
C TERMS USED TO CALCULATE WETTED SURFACE AREA 'AWET'
C
C
      WET1 = LWL*(2*T+B)*SQRT(CMID)
      WET2 = 0.453+0.4425*CB-0.2862*CMID
      WET3 = 0.003467*B/T
      WET4 = 0.3696*CWP
      WET5 = 2.38*ABULB/CB
      AWET = WET1*(WET2-WET3+WET4)+WET5
C
C
C CALCULATION OF EQUIVALENT APPENDAGE RESISTANCE FACTOR
C
C
      IF (IAPP .NE. 0) THEN
            IF (NAPP .EQ. 1) THEN
                  K2EQ=K2(1)
                  SUMAPP=ARAPP(1)
            ELSE
                  SUMAPP=0.
                  SUMPRD=0.
                  DO 22 I=1,NAPP
                        SUMPRD = SUMPRD+K2(I)*ARAPP(I)
                        SUMAPP = SUMAPP+ARAPP(I)
   22             CONTINUE
                  K2EQ=SUMPRD/SUMAPP
            END IF
         ELSE
            K2EQ=0.
      END IF
C
C
C CALCULATION OF REMAINING COEFFICIENTS REQUIRED FOR ESTIMATION OF
C TOTAL SHIP RESISTANCE
C
C TERMS FOR COEFFICIENT 'C17'
C
C
      C171 = 6919.3*CMID**-1.3346
      C172 = ((M/RHO)/LWL**3.)**2.00977
      C173 = (LWL/B-2.)**1.40692
      C17 = C171*C172*C173
C
C COEFFICIENT 'M3'
```

```
C
      M3 = (-7.2035*(B/LWL)**0.326869)*((T/B)**0.605375)
C
C COEFFICIENT 'C5'
C
      C5 = (1.-0.8*ATRANS/(B*T*CMID))
C
C COEFFICIENT 'C3'
C
      IF (ABULB .EQ. 0.) THEN
           C3=0.
         ELSE
           C3 = (0.56*ABULB**1.5)/(B*T*(0.31*SQRT(ABULB)+TFWD-HB))
      END IF
C
C COEFFICIENT 'C15'
C
      IF ((LWL**3./(M/RHO)) .LT. 512.) THEN
           C15=-1.69385
         ELSE IF ((LWL**3./(M/RHO)) .GT. 1726.91) THEN
           C15=0.
         ELSE
           C15=-1.69385+((LWL/(M/RHO)**(1./3.))-8.)/2.36
      END IF
C
C COEFFICIENT 'LAMBDA'
C
      IF ((LWL/B) .LE. 12.) THEN
           LAMBDA=1.446*CPRIS-0.03*LWL/B
         ELSE
           LAMBDA=1.446*CPRIS-0.36
      END IF
C
C COEFFICIENT 'C2'
C
      C2 = EXP(-1.89*SQRT(C3))
C
C COEFFICIENT 'C7'
C
      IF ((B/LWL) .LT. 0.11) THEN
           C7=0.229577*(B/LWL)**0.33333
         ELSE IF ((B/LWL) .GT. 0.25) THEN
           C7=0.5-0.0625*LWL/B
         ELSE
           C7=B/LWL
      END IF
C
C COEFFICIENT 'C16'
C
      IF (CPRIS .GT. 0.8) THEN
           C16=1.73014-0.7067*CPRIS
         ELSE
           C16=8.07981*CPRIS-13.8673*CPRIS**2.+6.984388*CPRIS**3.
      END IF
C
C TERMS USED FOR COEFFICIENT 'M1'
C
```

```
      MONE = 0.0140407*LWL/T
      MTWO = 1.75254*((M/RHO)**(1./3.))/LWL
      MTHR = 4.79323*B/LWL
      M1 = MONE-MTWO-MTHR-C16
C
C TERMS USED FOR WATERLINE ENTRANCE ANGLE 'ENTANG'
C
      ENT1 = -(LWL/B)**0.80856
      ENT2 = (1.-CWP)**0.30484
      ENT3 = (1.-CPRIS-0.0225*LCB)**0.6367
      ENT4 = (LRUN/B)**0.34574
      ENT5 = ((100.*M/RHO)/LWL**3.)**0.16302
      ENTANG = 1.+89.*EXP(ENT1*ENT2*ENT3*ENT4*ENT5)
C
C TERMS USED FOR COEFFICIENT 'C1'
C
      CONE = 2223105.*C7**3.78613
      CTWO = (T/B)**1.07961
      CTHR = (90.-ENTANG)**-1.37565
      C1 = CONE*CTWO*CTHR
C
C COEFFICIENT 'PB'
C
      PB = 0.56*SQRT(ABULB)/(TFWD-1.5*HB)
C
C COEFFICIENT 'C4'
C
      IF ((TFWD/LWL) .LE. 0.04) THEN
          C4=TFWD/LWL
        ELSE
          C4=0.04
      END IF
C
C TERMS USED TO CALCULATE CORRELATION ALLOWANCE COEFFICIENT 'CA'
C
      CA1 = 0.006*(LWL+100.)**-0.16
      CA2 = 0.003*SQRT(LWL/7.5)*CB**4.
      CA3 = C2*(0.04-C4)
      IF (SRUF .GT. 150.) THEN
          DELCA=(0.105*(SRUF*1.E-6)**(1./3.)-0.005579)/LWL**(1./3.)
        ELSE
          DELCA=0.
      END IF
      CA = (CA1-0.00205+CA2*CA3)+DELCA
C
C TO CALCULATE THE SHIP RESISTANCE, A 'DO-LOOP' IS USED TO INCREMENT
C THE SHIP SPEED.  VALUES OF FRICTIONAL RESISTANCE, WAVE-MAKING
C RESISTANCE, APPENDAGE RESISTANCE, ADDITIONAL RESISTANCE, AND TOTAL
C RESISTANCE ARE STORED IN ARRAYS.  EACH VALUE OF RESISTANCE
C CORRESPONDS TO A PARTICULAR SPEED.
C
      DO 33 I=1,ITR
C
C CALCULATE SPEED ARRAY SPD(I)
C
        SPD(I)=(VLOW+I-1)*0.51444
C
```

```
C CALCULATE FROUDE NUMBER 'FN' AND REYNOLD'S NUMBER 'RN'
C
        FN=SPD(I)/SQRT(GRAV*LWL)
        RN=SPD(I)*LWL/KVIS
C
C CALCULATE FRICTION RESISTANCE COEFFICIENT ACCORDING TO THE 1957
C I.T.T.C. LINE, AND A VALUE OF FRICTION RESISTANCE (NEWTONS)
C
        CFRIC=0.075/(LOG10(RN)-2.)**2.
        RFRIC(I)=CFRIC*0.5*RHO*AWET*SPD(I)**2.
C
C CALCULATE MODEL-SHIP CORRELATION RESISTANCE
C
        RCOR(I)=0.5*RHO*AWET*CA*SPD(I)**2.
C
C FROUDE NUMBER BASED ON TRANSOM IMMERSION
C
        IF (ATRANS .EQ. 0.) THEN
           FNTR=0.
        ELSE
           FNTR=SPD(I)/SQRT(2.*GRAV*ATRANS/(B+B*CWP))
        END IF
C
C COEFFICIENT 'C6'
C
        IF (FNTR .LT. 5.) THEN
           C6=0.2*(1.-0.2*FNTR)
        ELSE
           C6=0.
        END IF
C
C ADDITIONAL PRESSURE RESISTANCE DUE TO IMMERSED TRANSOM
C
        RTRAN(I)=0.5*RHO*ATRANS*C6*SPD(I)**2.
C
C FROUDE NUMBER BASED ON BULBOUS BOW IMMERSION
C
        TM1=TFWD-HB-0.25*SQRT(ABULB)
        TM2=GRAV*TM1+0.15*SPD(I)**2.
        FNBLB=SPD(I)/SQRT(TM2)
C
C ADDITIONAL RESISTANCE DUE TO BULBOUS BOW IMMERSION
C
        IF (ABULB .EQ. 0.) THEN
           RBULB(I)=0.
        ELSE
           RBLB1=EXP(-3.*ABS(PB)**-2.)
           RBLB2=FNBLB**3.*(ABULB**1.5)*RHO*GRAV
           RBLB3=1.+FNBLB**2.
           RBULB(I)=0.11*RBLB1*RBLB2/RBLB3
        END IF
C
C BOW THRUSTER RESISTANCE (TO BE ADDED TO APPENDAGE RESISTANCE)
C
        IF (DBOW .EQ. 0.) THEN
           RTHR=0.
        ELSE
```

```
            RTHR=RHO*PI*(DBOW**2.)*CBTH*SPD(I)**2.
        END IF
C
C APPENDAGE RESISTANCE
C
        RAPP(I)=0.5*RHO*SUMAPP*K2EG*CFRIC*SPD(I)**2.+RTHR
C
C COEFFICIENT 'M4'
C
        M4=C15*0.4*EXP(-0.034*FN**-3.29)
C
C WAVE-MAKING RESISTANCE
C
        IF (FN .GE. 0.55) THEN
            WAVE1=C17*C2*C5*M*GRAV
            WAVE2=M3*FN**-0.9
            WAVE3=M4*COS(LAMBDA*FN**-2.)
            RWAVE(I)=WAVE1*EXP(WAVE2+WAVE3)
          ELSE IF (FN .LE. 0.4) THEN
            WAVE1=C1*C2*C5*M*GRAV
            WAVE2=M1*FN**-0.9
            WAVE3=M4*COS(LAMBDA*FN**-2.)
            RWAVE(I)=WAVE1*EXP(WAVE2+WAVE3)
          ELSE
C
C CALCULATE WAVE RESISTANCE AT FN=0.4, AND FN=0.55, AND THEN USE THESE
C VALUES TO DETERMINE THE WAVE RESISTANCE FOR 0.4<FN<0.55 BY
C INTERPOLATION
C
            M44=C15*0.4*EXP(-0.034*0.4**-3.29)
            M45=C15*0.4*EXP(-0.034*0.55**-3.29)
            RW41=C1*C2*C5*M*GRAV
            RW42=EXP(M1*0.4**-0.9+M44*COS(LAMBDA*0.4**-0.2))
            RW4=RW41*RW42
            RW51=C17*C2*C5*M*GRAV
            RW52=EXP(M3*0.55**-0.9+M45*COS(LAMBDA*0.55**-0.2))
            RW5=RW51*RW52
            RWAVE(I)=RW4+(10.*FN-4.)*(RW5-RW4)/1.5
          END IF
C
C CALCULATE TOTAL RESISTANCE OF SHIP
C
     RTOT(I)=RWAVE(I)+RAPP(I)+RBULB(I)+RTRAN(I)+RCOR(I)+RFRIC(I)*(1.
    &+CFORM)
C
C CALCULATE EFFECTIVE HORSEPOWER
C
     EHP(I)=RTOT(I)*SPD(I)/1000.
  33 CONTINUE
C
C CALCULATE WAKE FRACTION AND THRUST DEDUCTION FRACTION
C
C COEFFICIENT 'CB'
C
     IF ((B/TAFT) .LT. 5.) THEN
         CB=B*AWET/(LWL*PDIA*TAFT)
       ELSE
```

```
               C8=AWET*(7.*B/TAFT-25.)/(LWL*PDIA*(B/TAFT-3.))
         END IF
C
C COEFFICIENT 'C9'
C
         IF (C8 .LE. 28.) THEN
               C9=C8
            ELSE
               C9=32.-(16./(C8-24.))
         END IF
C
C COEFFICIENT 'C11'
C
         IF ((TAFT/PDIA) .LE. 2.) THEN
               C11=TAFT/PDIA
            ELSE
               C11=0.0833333*(TAFT/PDIA)**3.+1.33333
         END IF
C
C COEFFICIENT 'C19'
C
         IF (CPRIS .LE. 0.7) THEN
               C19=(0.12997/(0.95-CB))-(0.11056/(0.95-CPRIS))
            ELSE
               C19=(0.18567/(1.3571-CMID))-0.71276+0.38648*CPRIS
         END IF
C
C COEFFICIENT 'C20'
C
         C20=1.+0.015*CSTERN
C
C COEFFICIENT 'CP1'
C
         CP1=1.45*CPRIS-0.315-0.0225*LCB
         IF (CP1 .GE. 1.) THEN
               CP1=0.
         END IF
C
C VISCOUS RESISTANCE COEFFICIENT 'CV'
C
         RNUM=VX1*LWL/KVIS
         CFRI=0.075/(LOG10(RNUM)-2.)**2.
         CV=(1.+CFORM)*CFRI+CA
C
C CALCULATE TERMS FOR WAKE FRACTION AND THRUST DEDUCTION FRACTION
C
         WFRA1=C9*C20*CV*LWL/TAFT
         WFRA2=0.93405*C11*CV/(1.-CP1)
         WFRA3=0.050776+WFRA2
         WFRA4=0.27915*C20*SQRT(B/(LWL*(1.-CP1)))
         WFRA5=C19*C20
         TFRA1=0.25014*(B/LWL)**0.28956
         TFRA2=(SQRT(B*T)/PDIA)**0.2624
         TFRA3=(1.-CPRIS+0.0225*LCB)**0.01762
         TFRA4=0.0015*CSTERN
C
C CALCULATE WAKE AND THRUST DEDUCTION FRACTION DEPENDING ON THE TYPE
```

```
C OF SCREW/STERN CONFIGURATION. THE VALUE OF THE INPUT VARIABLE 'CTYPE'
C WILL BE:
C                    CTYPE = 1  IF SINGLE SCREW, CONVENTIONAL STERN
C                    CTYPE = 2  IF SINGLE SCREW, OPEN STERN
C                    CTYPE = 3  IF TWIN SCREW
C
      IF (WFRAC .EQ. 0.) THEN
           IF (CTYPE .EQ. 1) THEN
                WFRAC=WFRA1*WFRA3+WFRA4+WFRA5
              ELSE IF (CTYPE .EQ. 2) THEN
                WFRAC=0.3*CB+10.*CV*CB-0.1
              ELSE
                WFRAC=0.3095*CB+10.*CV*CB-0.23*PDIA/SQRT(B*T)
           END IF
      END IF
      IF (TFRAC .EQ. 0.) THEN
           IF (CTYPE .EQ. 1) THEN
                TFRAC=TFRA1*TFRA2/TFRA3+TFRA4
              ELSE IF (CTYPE .EQ. 2) THEN
                TFRAC=0.10
              ELSE
                TFRAC=0.325*CB-0.1885*PDIA/SQRT(B*T)
           END IF
      END IF
C
C
C RETURN TO MAIN PROGRAM
C
C
      RETURN
      END
```

```
RESIST                                                28-Sep-1988 09:07:22    VAX FORTRAN V4.7-271                Page  29
                                                      28-Sep-1988 09:06:26    DUA1:[LANTOS]MANOEUVRE.FOR;1

PROGRAM SECTIONS

    Name                                Bytes   Attributes

  0 $CODE                                3912   PIC CON REL LCL   SHR   EXE   RD NOWRT LONG
  2 $LOCAL                                492   PIC CON REL LCL NOSHR NOEXE   RD   WRT LONG
  3 CONST                                  16   PIC OVR REL GBL   SHR NOEXE   RD   WRT LONG
  4 SHIP                                   48   PIC OVR REL GBL   SHR NOEXE   RD   WRT LONG
  5 PROP                                   20   PIC OVR REL GBL   SHR NOEXE   RD   WRT LONG
  6 RESDAT                                 36   PIC OVR REL GBL   SHR NOEXE   RD   WRT LONG

    Total Space Allocated                4524

ENTRY POINTS

    Address   Type  Name

  0-00000000        RESIST

VARIABLES

    Address    Type  Name            Address    Type  Name            Address    Type  Name            Address    Type  Name

  6-00000000   R*4   ABULB         5-00000008   R*4   AEAO          6-00000004   R*4   ATRANS               **     R*4   AWET
  4-00000010   R*4   B                     **   R*4   C1            2-0000002C   R*4   C11                  **     R*4   C14
  2-00000014   R*4   C15           2-00000018   R*4   C16                   **   R*4   C17                  **     R*4   C171
          **   R*4   C172                  **   R*4   C173          2-00000030   R*4   C19                  **     R*4   C2
          **   R*4   C20           2-00000010   R*4   C3            2-0000001C   R*4   C4                   **     R*4   C5
          **   R*4   C6                    **   R*4   C7                    **   R*4   C8           2-00000028     R*4   C9
          **   R*4   CA                    **   R*4   CA1                   **   R*4   CA2                  **     R*4   CA3
  4-00000014   R*4   CB            6-00000014   R*4   CBTH        AP-00000040@   R*4   CFORM                **     R*4   CFRI
          **   R*4   CFRIC         4-00000028   R*4   CMID                  **   R*4   CONE                 **     R*4   CP1
          **   R*4   CPRIS         6-0000001C   I*4   CSTERN                **   R*4   CTHR                 **     R*4   CTWO
  6-00000020   I*4   CTYPE                 **   R*4   CV            4-00000024   R*4   CWP          6-00000018     R*4   DBOW
  2-00000020   R*4   DELCA         4-0000002C   R*4   DEPTH                 **   R*4   ENT1                 **     R*4   ENT2
          **   R*4   ENT3                  **   R*4   ENT4                  **   R*4   ENT5                 **     R*4   ENTANG
          **   R*4   FN                    **   R*4   FNBLB                 **   R*4   FNTR                 **     R*4   FORM1
          **   R*4   FORM2                 **   R*4   FORM3                 **   R*4   FORM4                **     R*4   FORM5
  3-00000004   R*4   GRAV          6-00000010   R*4   HB                    **   I*4   I          AP-00000018@     I*4   IAPP
AP-0000000C@   I*4   ITR           2-00000004   R*4   K2EG          3-0000000C   R*4   KVIS         2-00000000     R*4   LAMBDA
  4-00000020   R*4   LCB           4-00000008   R*4   LPP                   **   R*4   LRUN         4-0000000C     R*4   LWL
  4-00000018   R*4   M                     **   R*4   M1                    **   R*4   M3                   **     R*4   M4
          **   R*4   M44                   **   R*4   M45           4-0000001C   R*4   META                 **     R*4   MONE
          **   R*4   MTHR                  **   R*4   MTWO        AP-00000014@   I*4   NAPP         5-00000004     I*4   NBLADE
          **   R*4   PB            5-00000000   R*4   PDIA          5-0000000C   R*4   PDRAT        3-00000008     R*4   PI
          **   R*4   RBLB1                 **   R*4   RBLB2                 **   R*4   RBLB3        3-00000000     R*4   RHO
          **   R*4   RN                    **   R*4   RNUM                  **   R*4   RTHR                 **     R*4   RW4
          **   R*4   RW41                  **   R*4   RW42                  **   R*4   RW5                  **     R*4   RW51
          **   R*4   RW52          6-0000000C   R*4   SRUF          2-0000000C   R*4   SUMAPP               **     R*4   SUMPRD
AP-00000008@   R*4   T             4-00000000   R*4   TAFT                  **   R*4   TFRA1                **     R*4   TFRA2
          **   R*4   TFRA3                 **   R*4   TFRA4       AP-0000004C@   R*4   TFRAC        4-00000004     R*4   TFWD
          **   R*4   TM1                   **   R*4   TM2           6-00000008   I*4   VLOW       AP-00000004@     R*4   VX1
          **   R*4   WAVE1                 **   R*4   WAVE2                 **   R*4   WAVE3                **     R*4   WET1
          **   R*4   WET2                  **   R*4   WET3                  **   R*4   WET4                 **     R*4   WET5
          **   R*4   WFRA1                 **   R*4   WFRA2                 **   R*4   WFRA3                **     R*4   WFRA4
```

```
      **       R*4  WFRA5           AP-00000048@ R*4  WFRAC           5-00000010  R*4  XPROPR

ARRAYS

    Address   Type  Name                     Bytes  Dimensions

 AP-0000001C@ R*4   ARAPP                       **   (*)
 AP-00000044@ R*4   EHP                         **   (*)
 AP-00000010@ R*4   K2                          **   (*)
 AP-00000024@ R*4   RAPP                        **   (*)
 AP-00000028@ R*4   RBULB                       **   (*)
 AP-00000030@ R*4   RCOR                        **   (*)
 AP-00000034@ R*4   RFRIC                       **   (*)
 AP-00000038@ R*4   RTOT                        **   (*)
 AP-0000002C@ R*4   RTRAN                       **   (*)
 AP-00000020@ R*4   RWAVE                       **   (*)
 AP-0000003C@ R*4   SPD                         **   (*)

LABELS

    Address    Label        Address    Label        Address    Label

      **        11            **        22            **        33

FUNCTIONS AND SUBROUTINES REFERENCED

  Type  Name              Type  Name              Type  Name              Type  Name

   R*4  MTH$ALOG10         R*4  MTH$COS            R*4  MTH$EXP            R*4  MTH$SQRT
```

```
C
C
C*************************************************************************
C
C
C                              SUBROUTINE HYDER
C
C
C*************************************************************************
C
C
      SUBROUTINE HYDER(T,TAU,YV,YR,YVR,YVV,YRR,NVVR,NRR,NVRR,NV,NR,NPHI
     &,NVPHI,NRPHI)
C
C
C THIS SUBROUTINE CALCULATES THE NON-DIMENSIONAL HYDRODYNAMIC
C DERIVATIVES REQUIRED TO CALCULATE THE FORCES ACTING ON THE SHIP,
C DURING A MANOEUVRE.  THE FORMULAE ARE FROM REFERENCE 1 OF THE MAIN REPORT.
C
C THE INPUT VARIABLES ARE:
C
C             1) T      - Mean draft of the ship (meters).
C
C             2) TAU    - Trim of the ship, which is equal to the draft
C                           aft minus the draft forward (meters).
C
C THE OUTPUT VARIABLES ARE:
C
C             1) YV,YR  - Linear derivatives of sway force 'Y' with
C                           respect to sway speed 'V' and yaw rate 'R'.
C
C             2) YVR    - Non-linear derivatives of sway force 'Y'
C                YVV        with respect to the sway speed and yaw rate.
C                YRR
C
C             3) NV,NR  - Linear derivatives of yaw moment 'N' with
C                NPHI       sway speed, yaw rate, and angle of heel.
C
C             4) NVVR   - Non-linear derivatives of yaw moment with respect
C                NRR        to sway speed, yaw rate and angle of heel.
C                NVRR
C                NVPHI
C                NRPHI
C
C COMMON BLOCK OF DATA, DECLARE REAL AND INTEGER VARIABLES
C
C
      COMMON /CONST/ RHO,GRAV,PI,KVIS
      COMMON /SHIP/ TAFT,TFWD,LPP,LWL,B,CB,M,META,LCB,CWP,CMID,DEPTH
C
C
C DECLARE VARIABLES
C
C
      REAL NVVR,NRR,NVRR,NV,NR,NVPHI,NRPHI,NPHI,K,LBETA
      REAL LPP,LWL,M,META,LCB,KVIS
C
```

```
C
C INITIALIZE VARIABLES
C
C
      YV = 0.
      YR = 0.
      YVR = 0.
      YVV = 0.
      YRR = 0.
      NV = 0.
      NR = 0.
      NPHI = 0.
      NVVR = 0.
      NRR = 0.
      NVRR = 0.
      NVPHI = 0.
      NRPHI = 0.
C
C
C CALCUALTE THE VALUES OF THE DERIVATIVES
C
C
      K = 2.*T/LPP
      LBETA = K/(PI*K/2.+1.4*CB*B/LPP)
      YV = -(PI*K/2.+1.4*CB*B/LPP)*(1.+(2.*TAU/(3.*T)))
      YR = (PI*K/4.)*(1.+0.8*TAU/T)
      YVR = -(-1.82*(1.-CB)*T/B+0.447)
      YVV = -(6.49*(1.-CB)*T/B -0.0795)
      YRR = -0.4664*(1.-CB)*T/B
      NVVR = -(3.25*CB*B/LPP-0.35+((LPP/(CB*B))**6.)*1.E-7)
      NVRR = -(-0.444*CB*T/B+0.064)
      NRR = -(1.7*(ABS(CB*B/LPP-0.157))**1.5+0.01)
      NV = -K*(1.-(0.27/LBETA)*TAU/T)
      NR = -(0.54*K-K**2.)*(1.+0.30*TAU/T)
      NPHI = -0.0076
      NRPHI = -2.36*NR
      NVPHI = 1.716*NV
C
C
C RETURN TO MAIN PROGRAM
C
C
      RETURN
      END
```

```
PROGRAM SECTIONS

    Name                                  Bytes   Attributes

  0 $CODE                                   464   PIC CON REL LCL   SHR    EXE   RD NOWRT LONG
  3 CONST                                    16   PIC OVR REL GBL   SHR NOEXE   RD   WRT LONG
  4 SHIP                                     48   PIC OVR REL GBL   SHR NOEXE   RD   WRT LONG

    Total Space Allocated                   528

ENTRY POINTS

    Address   Type   Name

  0-00000000         HYDER

VARIABLES

    Address   Type   Name                 Address   Type   Name                 Address   Type   Name                 Address   Type   Name

  4-00000010   R*4   B               4-00000014   R*4   CB               4-00000028   R*4   CMID               4-00000024   R*4   CWP
  4-0000002C   R*4   DEPTH           3-00000004   R*4   GRAV                     **   R*4   K                  3-0000000C   R*4   KVIS
          **   R*4   LBETA           4-00000020   R*4   LCB              4-00000008   R*4   LPP                4-0000000C   R*4   LWL
  4-00000018   R*4   M               4-0000001C   R*4   META            AP-00000034@  R*4   NPHI              AP-00000030@  R*4   NR
 AP-0000003C@  R*4   NRPHI          AP-00000024@  R*4   NRR             AP-0000002C@  R*4   NV                AP-00000038@  R*4   NVPHI
 AP-00000028@  R*4   NVRR           AP-00000020@  R*4   NVVR             3-00000008   R*4   PI                 3-00000000   R*4   RHO
 AP-00000004@  R*4   T               4-00000000   R*4   TAFT            AP-00000008@  R*4   TAU                4-00000004   R*4   TFWD
 AP-00000010@  R*4   YR             AP-0000001C@  R*4   YRR             AP-0000000C@  R*4   YV                AP-00000014@  R*4   YVR
 AP-00000018@  R*4   YVV
```

```
C
C
C***********************************************************************
C
C
C                             SUBROUTINE JKTKG
C
C
C***********************************************************************
C
C
      SUBROUTINE JKTKG(WPO,Y,KT,KG,JADV,WP)
C
C
C THIS SUBROUTINE CALCULATES THE ADVANCE COEFFICIENT 'JADV', THRUST
C COEFFICIENT 'KT', AND TORQUE COEFFICIENT 'KG'.  THESE PARAMETERS
C ARE USED FOR DETERMINING THE HYDRODYNAMIC FORCES ACTING ON THE SHIP.
C
C THE INPUT VARIABLES ARE:
C
C               1) WPO    - Propeller wake fraction in straight running
C                            condition.
C
C               2) Y      - Array of dependent variables. (Refer to the User
C                            Manual for a complete description.)
C
C THE OUTPUT VARIABLES ARE:
C
C               1) KT     - Propeller thrust coefficient.
C
C               2) KG     - Propeller torque coefficient.
C
C               3) JADV   - Speed of advance coefficient.
C
C               4) WP     - Effective propeller wake fraction.
C
C DIMENSION VARIABLES
C
      DIMENSION Y(10),SKT(39),SKG(47)
C
C COMMON BLOCKS OF DATA
C
      COMMON /SHIP/ TAFT,TFWD,LPP,LWL,B,CB,M,META,LCB,CWP,CMID,DEPTH
      COMMON /PROP/ PDIA,NBLADE,AEAO,PDRAT,XPROPR
C
C DECLARE REAL VARIABLES
C
      REAL JADV,KT,KG,LPP,LWL,M,META,LCB
C
C INITIALIZE SKT AND SKG
C
      DO 11 I=1,39
         SKT(I)=0.
   11 CONTINUE
      DO 22 I=1,47
         SKG(I)=0.
   22 CONTINUE
```

```
C
C INFLOW ANGLE AT THE PROPELLER 'BETAP'
C
      BETA = ATAN(-Y(3)/Y(1))
      BETAP = BETA+((XPROPR/LPP)*(Y(5)*LPP/SQRT(Y(1)**2.+Y(3)**2.)))
C
C EFFECTIVE WAKE FRACTION 'WP'
C
      WP = WPO*EXP(-4.0*BETAP**2.)
C
C ADVANCE COEFFICIENT 'JADV'
C
      JADV = Y(1)*(1.-WP)/(Y(9)*PDIA)
C
C CALCULATE 'KT' AND 'KQ' USING POLYNOMIALS OF WAGENINGEN B-SERIES
C SCREW PROPELLERS, AS DERIVED IN REFERENCE 17 OF THE MAIN REPORT.
C
         SKT(1) = 8.80496E-3
         SKT(2) = -0.204554*JADV
         SKT(3) = 0.166351*PDRAT
         SKT(4) = 0.158114*PDRAT**2.
         SKT(5) = -0.147581*(JADV**2.)*AEAO
         SKT(6) = -0.481497*JADV*PDRAT*AEAO
         SKT(7) = 0.415437*(PDRAT**2.)*AEAO
         SKT(8) = 0.0144043*NBLADE
         SKT(9) = -0.0530054*(JADV**2.)*NBLADE
         SKT(10) = 0.0143481*PDRAT*NBLADE
         SKT(11) = 0.0606826*JADV*PDRAT*NBLADE
         SKT(12) = -0.0125894*AEAO*NBLADE
         SKT(13) = 0.0109689*JADV*AEAO*NBLADE
         SKT(14) = -0.133698*PDRAT**3.
         SKT(15) = 6.38407E-3*PDRAT**6.
         SKT(16) = -1.32718E-3*(JADV**2.)*(PDRAT**6.)
         SKT(17) = 0.168496*(JADV**3.)*AEAO
         SKT(18) = -0.0507214*AEAO**2.
         SKT(19) = 0.0854559*(JADV**2.)*(AEAO**2.)
         SKT(20) = -0.0504475*(JADV**3.)*(AEAO**2.)
         SKT(21) = 0.010465*JADV*(PDRAT**6.)*(AEAO**2.)
         SKT(22) = -6.48272E-3*(JADV**2.)*(PDRAT**6.)*(AEAO**2.)
         SKT(23) = -8.41728E-3*(PDRAT**3.)*NBLADE
         SKT(24) = 0.0168424*JADV*(PDRAT**3.)*NBLADE
         SKT(25) = -1.02296E-3*(JADV**3.)*(PDRAT**3.)*NBLADE
         SKT(26) = -0.0317791*(PDRAT**3.)*AEAO*NBLADE
         SKT(27) = 0.018604*JADV*(AEAO**2.)*NBLADE
         SKT(28) = -4.10798E-3*(PDRAT**2.)*(AEAO**2.)*NBLADE
         SKT(29) = -6.06848E-4*NBLADE**2.
         SKT(30) = -4.9819E-3*JADV*NBLADE**2.
         SKT(31) = 0.0025983*JADV**2.*(NBLADE**2.)
         SKT(32) = -5.60528E-4*JADV**3.*(NBLADE**2.)
         SKT(33) = -1.63652E-3*JADV*(PDRAT**2.)*NBLADE**2.
         SKT(34) = -3.28787E-4*JADV*(PDRAT**6.)*NBLADE**2.
         SKT(35) = 1.16502E-4*JADV**2.*(PDRAT**6.)*NBLADE**2.
         SKT(36) = 6.90904E-4*AEAO*(NBLADE**2.)
         SKT(37) = 4.21749E-3*(PDRAT**3.)*AEAO*(NBLADE**2.)
         SKT(38) = 5.65229E-5*(JADV**3.)*(PDRAT**6.)*AEAO*(NBLADE**2.)
         SKT(39) = -1.46564E-3*(PDRAT**3.)*(AEAO**2.)*(NBLADE**2.)
C
```

```
C SUMMATION OF ALL 'KT' TERMS
C
      SUMKT = 0.0
      DO 33 I=1,39
         SUMKT = SUMKT+SKT(I)
   33 CONTINUE
C
C 'KG' POLYNOMIAL
C
         SKG(1) = 0.00379368
         SKG(2) = 8.86523E-3*JADV**2.
         SKG(3) = -0.032241*JADV*PDRAT
         SKG(4) = 0.00344778*PDRAT**2.
         SKG(5) = -0.0408811*PDRAT*AEAO
         SKG(6) = -0.108009*JADV*PDRAT*AEAO
         SKG(7) = -0.0885381*(JADV**2.)*PDRAT*AEAO
         SKG(8) = 0.188561*(PDRAT**2.)*AEAO
         SKG(9) = -0.00370871*JADV*NBLADE
         SKG(10) = 0.00513696*PDRAT*NBLADE
         SKG(11) = 0.0209449*JADV*PDRAT*NBLADE
         SKG(12) = 0.00474319*(JADV**2.)*PDRAT*NBLADE
         SKG(13) = -0.00723408*(JADV**2.)*AEAO*NBLADE
         SKG(14) = 0.00438388*JADV*PDRAT*AEAO*NBLADE
         SKG(15) = -0.0269403*(PDRAT**2.)*AEAO*NBLADE
         SKG(16) = 0.0558082*(JADV**3.)*AEAO
         SKG(17) = 0.0161886*(PDRAT**3.)*AEAO
         SKG(18) = 0.00318086*JADV*(PDRAT**3.)*AEAO
         SKG(19) = 0.015896*AEAO**2.
         SKG(20) = 0.0471729*JADV*(AEAO**2.)
         SKG(21) = 0.0196283*(JADV**3.)*(AEAO**2.)
         SKG(22) = -0.0502782*PDRAT*(AEAO**2.)
         SKG(23) = -0.030055*(JADV**3.)*PDRAT*(AEAO**2.)
         SKG(24) = 0.0417122*(JADV**2.)*(PDRAT**2.)*(AEAO**2.)
         SKG(25) = -0.0397722*(PDRAT**3.)*(AEAO**2.)
         SKG(26) = -0.00350024*(PDRAT**6.)*(AEAO**2.)
         SKG(27) = -0.0106854*(JADV**3.)*NBLADE
         SKG(28) = 0.00110903*(JADV**3.)*(PDRAT**3.)*NBLADE
         SKG(29) = -3.13912E-4*(PDRAT**6.)*NBLADE
         SKG(30) = 0.0035985*(JADV**3.)*AEAO*NBLADE
         SKG(31) = -1.42121E-3*(PDRAT**6.)*AEAO*NBLADE
         SKG(32) = -3.83637E-3*JADV*(AEAO**2.)*NBLADE
         SKG(33) = 0.0126803*(PDRAT**2.)*(AEAO**2.)*NBLADE
         SKG(34) = -3.18278E-3*(JADV**2.)*(PDRAT**3.)*(AEAO**2.)*NBLADE
         SKG(35) = 0.00334268*(PDRAT**6.)*(AEAO**2.)*NBLADE
         SKG(36) = -1.83491E-3*JADV*PDRAT*(NBLADE**2.)
         SKG(37) = 1.12451E-4*(JADV**3.)*(PDRAT**2.)*(NBLADE**2.)
         SKG(38) = -2.97228E-5*(JADV**3.)*(PDRAT**6.)*(NBLADE**2.)
         SKG(39) = 2.69551E-4*JADV*AEAO*(NBLADE**2.)
         SKG(40) = 8.3265E-4*(JADV**2.)*AEAO*(NBLADE**2.)
         SKG(41) = 0.00155334*(PDRAT**2.)*AEAO*(NBLADE**2.)
         SKG(42) = 3.02683E-4*(PDRAT**6.)*AEAO*(NBLADE**2.)
         SKG(43) = -1.843E-4*(AEAO**2.)*(NBLADE**2.)
         SKG(44) = -4.25399E-4*(PDRAT**3.)*(AEAO**2.)*(NBLADE**2.)
         SKG(45) = 8.69243E-5*(JADV**3.)*(PDRAT**3.)*(AEAO**2.)*NBLADE**2.
         SKG(46) = -4.659E-4*(PDRAT**6.)*(AEAO**2.)*(NBLADE**2.)
         SKG(47) = 5.5419E-5*JADV*(PDRAT**6.)*(AEAO**2.)*(NBLADE**2.)
C
```

```
C SUMMATION OF ALL 'KG' TERMS
C
      SUMKG = 0.0
      DO 44 I=1,47
         SUMKG = SUMKG+SKG(I)
   44 CONTINUE
C
C CALCULATION OF A CORRECTION FACTOR TO ADJUST 'KT' AND 'KG'
C POLYNOMIALS, CORRESPONDING TO ACTUAL REYNOLD'S NUMBER. METHOD
C OUTLINED IN REFERENCES 14,15 OF THE MAIN REPORT.
C
C PROPELLER CHORD LENGTH
C
      CORD = 2.073*AEAO*PDIA/NBLADE
C
C PROPELLER THICKNESS/CHORD LENGTH RATIO
C
      TCORD = (0.0185-0.00125*NBLADE)*PDIA/CORD
C
C PROPELLER ROUGHNESS CONSTANT
C
      PROUGH = 0.00003
C
C DRAG COEFFICIENT CORRECTION
C
      T1 = 2.+4.*TCORD
      T2 = LOG10(CORD/PROUGH)
      T3 = (1.189+1.62*T2)**-2.5
      CDRAG = T1*(0.003605-T3)
C
C CORRECTION TO 'KT' AND 'KG'
C
      DELKT = CDRAG*0.3*PDRAT*CORD*NBLADE/PDIA
      DELKG = CDRAG*0.25*CORD*NBLADE/PDIA
C
C VALUES OF 'KT' AND 'KG'
C
      KT = SUMKT+DELKT
      KG = SUMKG-DELKG
C
C RETURN TO MAIN PROGRAM
C
      RETURN
      END
```

```
JKTKG                                                  28-Sep-1988 09:07:22    VAX FORTRAN V4.7-271                Page  38
                                                       28-Sep-1988 09:06:26    DUA1:[LANTOS]MANOEUVRE.FOR;1

PROGRAM SECTIONS

    Name                                   Bytes   Attributes

  0 $CODE                                   1890   PIC CON REL LCL   SHR   EXE   RD NOWRT LONG
  2 $LOCAL                                   368   PIC CON REL LCL NOSHR NOEXE   RD   WRT LONG
  3 SHIP                                      48   PIC OVR REL GBL   SHR NOEXE   RD   WRT LONG
  4 PROP                                      20   PIC OVR REL GBL   SHR NOEXE   RD   WRT LONG

    Total Space Allocated                   2326

ENTRY POINTS

    Address   Type  Name

  0-00000000        JKTKG

VARIABLES

    Address   Type  Name              Address   Type  Name              Address   Type  Name              Address   Type  Name

  4-00000008  R*4   AEAD           3-00000010  R*4   B                     **       R*4   BETA                  **       R*4   BETAP
  3-00000014  R*4   CB                  **     R*4   CDRAG           3-00000028  R*4   CMID                  **       R*4   CORD
  3-00000024  R*4   CWP                 **     R*4   DELKG                 **     R*4   DELKT          3-0000002C  R*4   DEPTH
      **      I*4   I            AP-00000014@ R*4   JADV          AP-00000010@ R*4   KG            AP-0000000C@ R*4   KT
  3-00000020  R*4   LCB            3-00000008  R*4   LPP             3-0000000C  R*4   LWL            3-00000018  R*4   M
  3-0000001C  R*4   META           4-00000004  I*4   NBLADE          4-00000000  R*4   PDIA           4-0000000C  R*4   PDRAT
      **      R*4   PROUGH              **     R*4   SUMKG                 **     R*4   SUMKT          2-00000158  R*4   T1
      **      R*4   T2                  **     R*4   T3              3-00000000  R*4   TAFT                 **      R*4   TCORD
  3-00000004  R*4   TFWD         AP-00000018@ R*4   WP            AP-00000004@ R*4   WPD            4-00000010  R*4   XPROPR

ARRAYS

    Address   Type  Name                 Bytes  Dimensions

  2-0000009C  R*4   SKG                    188  (47)
  2-00000000  R*4   SKT                    156  (39)
 AP-00000008@ R*4   Y                       40  (10)

LABELS

    Address    Label        Address    Label        Address    Label        Address    Label

      **       11               **     22               **     33               **     44

FUNCTIONS AND SUBROUTINES REFERENCED

   Type  Name             Type  Name             Type  Name             Type  Name

   R*4   MTH$ALOG10       R*4   MTH$ATAN         R*4   MTH$EXP          R*4   MTH$SQRT
```

```
C
C
C**********************************************************************************
C
C
C                             SUBROUTINE RUDANG
C
C
C**********************************************************************************
C
C
      SUBROUTINE RUDANG(ITIME,TIME,TIMEFL,MNVRE,COUNT,SPIRAL,ZIGZAG,
     &ANGMAX,DELTANG,ISPIR,Y,YWRATE,YAWANG,ORDANG,RUDRATE,STEP,RANGLE,
     &RESSPIR,END,WIDTH1)
C
C
C THIS SUBROUTINE CALCULATES THE RUDDER ANGLE AT ANY TIME 'T', DURING
C EACH OF THE MANOEUVRES.
C
C INPUT VARIABLES ARE:
C
C
C               1) ITIME    - Variable used as a counter in the subroutine.
C
C               2) TIME     - Current value of time during the simulation
C                              (secs).
C
C               3) TIMEFL   - Flag to indicate when the computer should
C                              check for a constant yaw rate during the
C                              spiral manoeuvre (secs).
C
C               4) MNVRE    - Indicates the type of manoeuvre being simulated.
C
C               5) COUNT    - Indicates when the first half of the spiral
C                              manoeuvre has been completed.
C
C               6) SPIRAL   - Variable used to increment the rudder angle
C                              during the spiral manoeuvre.
C
C               7) ZIGZAG   - Counter which indicates the total number of
C                              rudder executions during the zigzag manoeuvre.
C
C               8) ANGMAX   - Variable used to determine the end of the
C                              spiral manoeuvre (degrees).
C
C               9) DELTANG  - The increment used to change the rudder angle
C                              during the spiral manoeuvre (degrees).
C
C              10) ISPIR    - Counter which indicates the total number of
C                              rudder angle changes during the spiral
C                              manoeuver.
C
C              11) Y        - Vector containing the current values of the
C                              dependent variables used during the time
C                              simulation.
C
C              12) YWRATE   - Vector containing the values of yaw rate at
```

```
C                           each time step during the simulation (rad./sec.).
C
C               13) YAWANG   - Vector containing the values of yaw angle at
C                              each time step during the simulation (radians).
C
C               14) ORDANG   - Initial rudder angle (degrees).
C
C               15) RUDRATE  - Rate at which the rudder angle can be applied.
C                              (deg./sec)
C
C               16) STEP     - Time step increment (secs.).
C
C THE OUTPUT VARIABLES ARE:
C
C                1) RANGLE   - Current value of the rudder angle (radians).
C
C                2) RESSPIR  - Vector containing the results of the spiral
C                              manoeuvre.
C
C                3) END      - Flag indicating when the end of the manoeuvre
C                              has occurred.
C
C                4) WIDTH1   - Distance the ship has travelled from the base
C                              course, in the global y-direction.  Used in
C                              subroutine TEST to determine the overshoot width
C                              of path.
C
C COMMON BLOCK OF DATA
C
      COMMON /CONST/ RHO,GRAV,PI,KVIS
C
C DIMENSION/DECLARE VARIABLES
C
      DIMENSION Y(10),YWRATE(4000),YAWANG(4000),RESSPIR(20)
      REAL KVIS
C
C DETERMINE THE RUDDER ANGLE AT ANY TIME DURING THE MANOEUVRE
C
      IF (MNVRE .EQ. 1) THEN
         IF (TIME .EQ. 0.) THEN
            RANGLE=0.
         ELSE IF (TIME .LE. (ABS(ORDANG)/RUDRATE)) THEN
            IF (ORDANG .GT. 0.) THEN
               RANGLE=RUDRATE*TIME*PI/180.
            ELSE
               RANGLE=-RUDRATE*TIME*PI/180.
            END IF
         ELSE
            RANGLE=ORDANG*PI/180.
         END IF
C
C
C TURNING CIRCLE MANOEUVRE - RUDDER ANGLE AFTER THE FIRST TIME STEP
C                            IS APPLIED AT THE SPECIFIED RUDDER RATE,
C                            UNTIL IT REACHES A MAXIMUM VALUE OF ORDANG.
C
C
```

```
          IF (ABS(Y(6)) .GE. 6.5) THEN
               END=1.
               WRITE(20,*)
               WRITE(20,*) 'END OF TURNING CIRCLE MANOEUVRE'
               WRITE(20,*)
          END IF
      END IF
      IF (MNVRE .EQ. 2) THEN
          IF (TIME .EQ. 0.) THEN
               RANGLE=0.
C
C Rudder angle is applied gradually during the initial stages of the
C zigzag manoeuvre.
C
             ELSE IF (TIME .LE. (ABS(ORDANG)/RUDRATE)) THEN
               IF (ORDANG .GT. 0.) THEN
                   RANGLE=RUDRATE*TIME*PI/180.
                  ELSE
                   RANGLE=-RUDRATE*TIME*PI/180.
               END IF
             ELSE
C
C The parameter 'ZIG' is a counter which is set to zero each time the
C rudder angle reaches a maximum value of 'ORDANG' or '-ORDANG'.  The
C program will now test the current ship's heading to determine if the
C rudder angle should be applied in the opposite direction.
C
               IF (ZIG .EQ. 0.) THEN
C
C Perform an initial check to see if the yaw angle at the current
C time step has the same sign, as the ordered rudder angle 'ORDANG'.
C
                    IF (((YAWANG(ITIME) .GE. 0.) .AND.
   &(ORDANG .GE. 0.)) .OR. ((YAWANG(ITIME) .LE. 0.) .AND.
   &(ORDANG .LE. 0.))) THEN
C
C Perform a check to see if the yaw angle at the current time step is
C within 0.5 degrees (.008 radians) of the ordered rudder angle 'ORDANG'
C
                        IF (ABS(YAWANG(ITIME)-ORDANG*PI/180.)
     &                    .LE. .008) THEN
C
C Determine the distance that the ship has travelled from the base course,
C in the global y-direction.  This value will be used in subroutine TEST
C to determine the overshoot width of path.
C
                          IF (WIDTH1 .EQ. 0.) THEN
                               WIDTH1=Y(4)
                          END IF
C
C Increment 'ZIG' and 'ZIGZAG'.  Apply the rudder angle according to the
C rudder rate.
C
                          ORDANG=-ORDANG
                          ZIG=ZIG+1.
                          ZIGZAG=ZIGZAG+1.
                          IF (ANGMAX .GT. 0.) THEN
```

```
                              RANGLE=(ANGMAX-RUDRATE*ZIG*STEP)*PI/180.
                             ELSE
                              RANGLE=(ANGMAX+RUDRATE*ZIG*STEP)*PI/180.
                            END IF
C
C Perform a check to see if the value of the rudder angle, ORDANG, is
C between the value of the yaw angle at the current time step, and the
C the previous time step.  If it is then change the rudder angle.
C
                           ELSE IF ((ABS(YAWANG(ITIME)) .GT.
   &ABS(ORDANG*PI/180.)) .AND. (ABS(YAWANG(ITIME-1)) .LT.
   &ABS(ORDANG*PI/180.))) THEN
C
C Determine the distance that the ship has travelled from the base course,
C in the global y-direction.  This value will be used in subroutine TEST
C to determine the overshoot width of path.
C
                            IF (WIDTH1 .EQ. 0.) THEN
                               WIDTH1=Y(4)
                            END IF
C
C Increment 'ZIG' and 'ZIGZAG'. Apply the rudder angle according to the
C rudder rate.
C
                            ORDANG=-ORDANG
                            ZIG=ZIG+1.
                            ZIGZAG=ZIGZAG+1.
                            IF (ANGMAX .GT. 0.) THEN
                              RANGLE=(ANGMAX-RUDRATE*ZIG*STEP)*PI/180.
                             ELSE
                              RANGLE=(ANGMAX+RUDRATE*ZIG*STEP)*PI/180.
                            END IF
                          END IF
                     END IF
C
C This loop is used to continue applying the rudder angle until it reaches
C the value of 'ORDANG' or '-ORDANG'.
C
                 ELSE IF (ZIG .LT. (2.*ABS(ANGMAX)/(RUDRATE*STEP)))THEN
                          ZIG=ZIG+1.
                          IF (ORDANG .GT. 0.) THEN
                               RANGLE=(-ORDANG+RUDRATE*ZIG*STEP)*PI/180.
                             ELSE
                               RANGLE=(-ORDANG-RUDRATE*ZIG*STEP)*PI/180.
                          END IF
C
C Check to see if the manoeuvre has been completed.
C
                          IF (ABS(ZIGZAG-5.) .LE. .001) THEN
                               WRITE (20,*)
                               WRITE (20,*) 'END OF ZIGZAG SIMULATION'
                               WRITE (20,*)
                               END=1.
                             ELSE
C
C Write the value of the rudder angle to the output file when it has
C been fully applied.
```

```
C
              IF (INT(ZIG) .EQ. INT(2.*ABS(ANGMAX)/(RUDRATE*STEP))) THEN
                    WRITE (20,*)
                    WRITE (20,*) 'RUDDER ANGLE IS',ORDANG
                    WRITE (20,*)
              END IF
                       END IF
                  ELSE
C
C Reset 'ZIG' to zero, and maintain the maximum rudder angle until the
C ship's yaw angle is equal to the current value of 'ORDANG'.
C
                     ZIG=0.
                     RANGLE=ORDANG*PI/180.
                  END IF
            END IF
      END IF
      IF (MNVRE .EQ. 3.) THEN
            IF (TIME .EQ. 0.) THEN
                  RANGLE=0.
C
C
C SPIRAL MANOEUVRE - DETERMINE THE TIME TO DECREASE, OR INCREASE, THE
C                    RUDDER ANGLE BY FIVE (5) DEGREES.  THE PROGRAM
C                    DOES NOT START TESTING FOR A CONSTANT RATE OF TURN
C                    'YWRATE' UNTIL TWO (2) MINUTES HAVE ELAPSED, FROM
C                    THE LAST RUDDER CHANGE.
C
C
C Perform a check to see if two minutes have elapsed.
C
                    ELSE IF ((TIME-TIMEFL) .GE. 121.) THEN
C
C Compare the yaw rate at the current time step to the yaw rate two (2)
C minutes earlier.  If they are within 0.05 deg/sec. (.001 rad/sec), then
C change the rudder angle.
C
                       IF(ABS(YWRATE(ITIME)-YWRATE(ITIME-120)) .LE. .001)THEN
C
C Store the value of yaw rate at the current time step, to use in a summary
C table of results.
C
                          ISPIR=ISPIR+1
                          RESSPIR(ISPIR)=YWRATE(ITIME)
C
C Change the rudder angle
C
                          TIMEFL=TIME
                          ORDANG=ORDANG-SPIRAL*DELTANG
                          WRITE(20,*)
                          WRITE(20,*) 'RUDDER ANGLE =',ORDANG
                          WRITE(20,*)
C
C If the parameter 'COUNT' is equal to '0', then the rudder angle is
C still approaching the inverse of its original value.  That is to say,
C the program has not completed the FIRST HALF of the manoeuvre.
C
```

```
                     IF (COUNT .EQ. O.) THEN
                         IF(ABS(ABS(ORDANG)-ABS(ANGMAX)) .LE. .001)THEN
                              SPIRAL=-SPIRAL
                              COUNT=COUNT+1.
                         END IF
                       ELSE IF (ABS(ORDANG-ANGMAX+SPIRAL*DELTANG)
     &                            .LE. .001) THEN
                         WRITE(20,*)
                         WRITE(20,*) 'END OF SPIRAL TEST'
                         WRITE(20,*)
                         END=1.
                     END IF
                END IF
              ELSE
                RANGLE=ORDANG*PI/180.
           END IF
      END IF
C
C RETURN TO MAIN PROGRAM
C
      RETURN
      END
```

```
PROGRAM SECTIONS

    Name                               Bytes   Attributes

  0 $CODE                               1279   PIC CON REL LCL   SHR   EXE   RD NOWRT LONG
  1 $PDATA                               102   PIC CON REL LCL   SHR NOEXE   RD NOWRT LONG
  2 $LOCAL                               124   PIC CON REL LCL NOSHR NOEXE   RD   WRT LONG
  3 CONST                                 16   PIC OVR REL GBL   SHR NOEXE   RD   WRT LONG

    Total Space Allocated               1521

ENTRY POINTS

    Address   Type  Name

  0-00000000        RUDANG

VARIABLES

    Address   Type  Name                Address   Type  Name                Address   Type  Name                Address   Type  Name

 AP-00000020@ R*4   ANGMAX           AP-00000014@ R*4   COUNT            AP-00000024@ R*4   DELTANG          AP-0000004C@ R*4   END
  3-00000004  R*4   GRAV             AP-00000028@ I*4   ISPIR            AP-00000004@ I*4   ITIME             3-0000000C  R*4   KVIS
 AP-00000010@ I*4   MNVRE            AP-00000038@ R*4   ORDANG            3-00000008  R*4   PI               AP-00000044@ R*4   RANGLE
  3-00000000  R*4   RHO              AP-0000003C@ R*4   RUDRATE          AP-00000018@ R*4   SPIRAL           AP-00000040@ R*4   STEP
 AP-00000008@ R*4   TIME             AP-0000000C@ R*4   TIMEFL           AP-00000050@ R*4   WIDTH1            2-00000000  R*4   ZIG
 AP-0000001C@ R*4   ZIGZAG
```

```
ARRAYS

    Address   Type  Name                     Bytes  Dimensions

 AP-000000048@ R*4  RESSPIR                     80  (20)
 AP-00000002C@ R*4  Y                           40  (10)
 AP-000000034@ R*4  YAWANG                   16000  (4000)
 AP-000000030@ R*4  YWRATE                   16000  (4000)
```

```
C
C
C*************************************************************************************
C
C
C                                SUBROUTINE RUDFOR
C
C
C*************************************************************************************
C
C
      SUBROUTINE RUDFOR(RANGLE, LAMDA, WPO, WRO, Y, WP, NPROP, FRN)
C
C
C THIS SUBROUTINE CALCULATES THE NORMAL FORCE 'FRN' ACTING ON THE RUDDER
C AT ANY TIME DURING THE MANOEUVRE.
C
C INPUT VARIABLES ARE:
C
C              1) RANGLE - Current value of the rudder angle (radians).
C
C              2) LAMDA  - Rudder aspect ratio.
C
C              3) WPO    - Propeller wake fraction.
C
C              4) WRO    - Rudder wake fraction.
C
C              5) Y      - Vector containing current values of the dependent
C                            variables used in the equations of motion.
C
C              6) WP     - Effective propeller wake fraction.
C
C              7) NPROP  - Number of propellers.
C
C OUTPUT VARIABLE IS:
C
C              1) FRN    - Rudder normal force (Newtons)
C
C DIMENSION VARIABLES
C
      DIMENSION Y(10)
C
C COMMON BLOCKS OF DATA
C
      COMMON /CONST/ RHO, GRAV, PI, KVIS
      COMMON /SHIP/ TAFT, TFWD, LPP, LWL, B, CB, M, META, LCB, CWP, CMID, DEPTH
      COMMON /PROP/ PDIA, NBLADE, AEAO, PDRAT, XPROPR
      COMMON /RUDR/ HRUD, ARUD, XR, ZR
C
C DECLARE VARIABLES
C
      REAL LAMDA, K2, KAY, KVIS, LPP, LWL, M, META, LCB, NPROP
C
C INITIALIZE FRN
C
      FRN=0.
C
```

```
C CALCULATE SPEED OF SHIP 'VSHIP'
C
      VSHIP=SQRT(Y(1)**2.+Y(3)**2.)
C
C CALCULATE CONSTANT 'K2' DEPENDENT UPON RUDDER ANGLE 'RANGLE'
C
      IF (RANGLE .LT. 0.) THEN
         K2=0.935
      ELSE
         K2=1.065
      END IF
C
C SLIP RATIO 'SLIP'
C
      SLIP=1.-Y(1)*(1.-WP)/(Y(9)*PDRAT*PDIA)
C
C CONSTANTS TO CALCULATE EFFECTIVE RUDDER INFLOW SPEED 'VERUD'
C
      PRRAT=PDIA/HRUD
      WR=WRO*WP/WPO
      KAY=0.6*(1.-WP)/(1.-WR)
      GS=PRRAT*KAY*(2.-(2.-KAY)*SLIP)*SLIP/(1.-SLIP)**2.
      VERUD=VSHIP*(1.-WR)*SQRT(1.+K2*GS)
C
C MODIFIED DRIFT ANGLE 'BETAR'
C
      BETA=ATAN(-Y(3)/Y(1))
      XPR=XR/LPP
      RPR=Y(5)*LPP/VSHIP
      BETAR=BETA-2.*XPR*RPR
C
C PROPELLER FLOW RECTIFICATION COEFFICIENT 'CPFLOW'
C
      CPFLOW=1./SQRT(1.+0.6*PRRAT*(2.-1.4*SLIP)*SLIP/(1.-SLIP)**2.)
C
C SHIP HULL FLOW RECTIFICATION COEFFICIENT 'CHFLOW'
C
      IF (ABS(BETAR) .LE. 1.11) THEN
         CS=0.45*ABS(BETAR)
      ELSE
         CS=0.5
      END IF
      CHFLOW=CPFLOW*CS
C
C CALCULATE 'ALPHAR'
C
      ALPHAR=RANGLE-CHFLOW*BETAR
C
C RUDDER NORMAL FORCE 'FRN'
C
      FN1=0.5*RHO*((6.13*LAMDA)/(LAMDA+2.25))
      IF (VERUD .EQ. 0.) THEN
         FN2=0.
      ELSE
         FN2=ARUD*(VERUD**2.)*SIN(ALPHAR)
      END IF
      FRN=FN1*FN2
      C
      C RUDDER NORMAL FORCE 'FRN' FOR TWIN SCREW SHIPS
      C
           IF (NPROP .EQ. 2.) THEN
                FRN=1.5*FRN
           END IF
      C
      C
      C RETURN TO MAIN PROGRAM
      C
      C
           RETURN
           END


PROGRAM SECTIONS

    Name                                      Bytes   Attributes

  0 $CODE                                       400   PIC CON REL LCL   SHR   EXE   RD NOWRT LONG
  2 $LOCAL                                       20   PIC CON REL LCL NOSHR NOEXE   RD   WRT LONG
  3 CONST                                        16   PIC OVR REL GBL   SHR NOEXE   RD   WRT LONG
  4 SHIP                                         48   PIC OVR REL GBL   SHR NOEXE   RD   WRT LONG
  5 PROP                                         20   PIC OVR REL GBL   SHR NOEXE   RD   WRT LONG
  6 RUDR                                         16   PIC OVR REL GBL   SHR NOEXE   RD   WRT LONG

    Total Space Allocated                       520

ENTRY POINTS

    Address   Type  Name

  0-00000000        RUDFOR

VARIABLES

    Address   Type  Name                 Address   Type  Name                 Address   Type  Name                 Address   Type  Name

  5-00000008  R*4   AEAD                      **     R*4   ALPHAR             6-00000004   R*4   ARUD               4-00000010   R*4   B
      **      R*4   BETA                      **     R*4   BETAR              4-00000014   R*4   CB                     **       R*4   CHFLOW
  4-00000028  R*4   CMID                      **     R*4   CPFLOW                 **       R*4   CS                 4-00000024   R*4   CWP
  4-0000002C  R*4   DEPTH                     **     R*4   FN1                    **       R*4   FN2              AP-00000020@   R*4   FRN
  3-00000004  R*4   GRAV                      **     R*4   GS                 6-00000000   R*4   HRUD                   **       R*4   K2
      **      R*4   KAY               3-0000000C     R*4   KVIS             AP-00000008@   R*4   LAMDA              4-00000020   R*4   LCB
  4-00000008  R*4   LPP               4-0000000C     R*4   LWL                4-00000018   R*4   M                  4-0000001C   R*4   META
  5-00000004  I*4   NBLADE          AP-0000001C@     R*4   NPROP              5-00000000   R*4   PDIA               5-0000000C   R*4   PDRAT
  3-00000008  R*4   PI                        **     R*4   PRRAT            AP-00000004@   R*4   RANGLE             3-00000000   R*4   RHO
      **      R*4   RPR                       **     R*4   SLIP               4-00000000   R*4   TAFT               4-00000004   R*4   TFWD
      **      R*4   VERUD                     **     R*4   VSHIP            AP-00000018@   R*4   WP               AP-0000000C@   R*4   WPO
      **      R*4   WR              AP-00000010@     R*4   WRO                    **       R*4   XPR                5-00000010   R*4   XPROPR
  6-00000008  R*4   XR                6-0000000C     R*4   ZR
```

```
ARRAYS

    Address   Type  Name                    Bytes  Dimensions

 AP-00000014@ R*4   Y                          40  (10)

FUNCTIONS AND SUBROUTINES REFERENCED

  Type  Name              Type  Name              Type  Name
   R*4  MTH$ATAN           R*4  MTH$SIN            R*4  MTH$SQRT
```

```
C
C
C********************************************************************************
C
C
C                               SUBROUTINE RUNGE
C
C
C********************************************************************************
C
C
      SUBROUTINE RUNGE (N,Y,F,X,H,M,K)
C
C
C THIS ROUTINE PERFORMS FOURTH ORDER RUNGE-KUTTA INTEGRATION USING GILL'S METHOD
C
C The routine was taken from the book 'Viscous Fluid Flow' by Frank M. White
C
      DIMENSION Y(10),F(10),Q(10)
      M=M+1
      GO TO (1,4,5,3,7),M
    1 DO 2 I=1,N
         Q(I)=0.0
    2 CONTINUE
      A=0.5
      GO TO 9
    3 A=1.707107
    4 X=X+0.5*H
    5 DO 6 I=1,N
         Y(I)=Y(I)+A*(F(I)*H-Q(I))
         Q(I)=2.0*A*H*F(I)+(1.0-3.0*A)*Q(I)
    6 CONTINUE
      A=0.2928932
      GO TO 9
    7 DO 8 I=1,N
         Y(I)=Y(I)+H*F(I)/6.0-Q(I)/3.0
    8 CONTINUE
      M=0
      K=2
      GO TO 10
    9 K=1
C
C
C RETURN TO THE MAIN PROGRAM
C
C
   10 RETURN
      END
```

```
PROGRAM SECTIONS

    Name                                   Bytes   Attributes

  0 $CODE                                    279   PIC CON REL LCL   SHR   EXE   RD NOWRT LONG
  2 $LOCAL                                    92   PIC CON REL LCL NOSHR NOEXE   RD   WRT LONG

    Total Space Allocated                    371

ENTRY POINTS

    Address   Type  Name

  0-00000000        RUNGE

VARIABLES

    Address   Type  Name                Address   Type  Name                Address   Type  Name                Address   Type  Name

  2-00000028  R*4   A             AP-00000014@ R*4   H                      **      I*4   I             AP-0000001C@ I*4   K
AP-00000018@  I*4   M             AP-00000004@ I*4   N             AP-00000010@ R*4   X

ARRAYS

    Address   Type  Name                   Bytes  Dimensions

AP-0000000C@  R*4   F                         40  (10)
  2-00000000  R*4   G                         40  (10)
AP-00000008@  R*4   Y                         40  (10)

LABELS

    Address   Label       Address   Label       Address   Label       Address   Label       Address   Label       Address   Label

  0-00000039  1              **     2      0-00000064  3         0-0000006B  4         0-00000074  5              **     6
  0-000000D4  7              **     8      0-000000CD  9         0-00000116  10
```

```
C
C
C***********************************************************************
C
C
C                          SUBROUTINE XTERMS
C
C
C***********************************************************************
C
C
      SUBROUTINE XTERMS(MY,Y,XRES,KT,TFRAC,FRN,RANGLE,VINIT,MX,NPROP,
     &                  XSUM)
C
C
C THIS SUBROUTINE CALCULATES THE TERMS USED IN THE DIFFERENTIAL EQUATION
C FOR DETERMINING THE ACCELERATION IN THE X-DIRECTION, AND ADDS THEM
C BEFORE RETURNING TO THE MAIN PROGRAM.
C
C INPUT VARIABLES ARE:
C
C              1) MY     - Added mass in the y-direction (kg).
C
C              2) MX     - Added mass in the x-direction (kg).
C
C              3) Y      - Vector containing current values of the dependent
C                          variables used in the equations of motion.
C
C              4) XRES   - Value of ship resistance at the initial approach
C                          speed of the manoeuvre (Newtons).
C
C              5) KT     - Propeller thrust coefficient.
C
C              6) TFRAC  - Thrust deduction fraction.
C
C              7) FRN    - Current value of rudder normal force (Newtons).
C
C              8) RANGLE - Current value of the rudder angle (radians).
C
C              9) VINIT  - Initial speed at the start of the manoeuvre (m/sec).
C
C             10) NPROP  - Number of propellers.
C
C OUTPUT VARIABLE IS;
C
C              1) XSUM   - Value of local x-acceleration of the ship (m/sec**2).
C
C DIMENSION VARIABLES
C
      DIMENSION Y(10)
C
C COMMON BLOCKS OF DATA
C
      COMMON /CONST/ RHO,GRAV,PI,KVIS
      COMMON /SHIP/ TAFT,TFWD,LPP,LWL,B,CB,M,META,LCB,CWP,CMID,DEPTH
      COMMON /PROP/ PDIA,NBLADE,AEAO,PDRAT,XPROPR
C
```

```
C DECLARE VARIABLES
C
      REAL MY,KT,MX,KVIS,LPP,LWL,M,META,LCB,NPROP
C
C CALCULATE TERMS FOR THE X-ACCELERATION EQUATION
C
      XTERM1=M*Y(3)*Y(5)
      XTERM2=0.62*MY*Y(3)*Y(5)
      XTERM3=-(XRES/VINIT**2.)*Y(1)*ABS(Y(1))
      XTERM4=NPROP*(1.-TFRAC)*RHO*(Y(9)**2.)*(PDIA**4.)*KT
      XTERM5=-FRN*SIN(RANGLE)
      XTERM6=M+MX
C
C SUMMATION OF ALL TERMS
C
      XSUM=(XTERM1+XTERM2+XTERM3+XTERM4+XTERM5)/XTERM6
C
C RETURN TO MAIN PROGRAM
C
      RETURN
      END


PROGRAM SECTIONS

    Name                                          Bytes   Attributes

  0 $CODE                                           180   PIC CON REL LCL   SHR   EXE   RD NOWRT LONG
  2 $LOCAL                                           20   PIC CON REL LCL NOSHR NOEXE   RD   WRT LONG
  3 CONST                                            16   PIC OVR REL GBL   SHR NOEXE   RD   WRT LONG
  4 SHIP                                             48   PIC OVR REL GBL   SHR NOEXE   RD   WRT LONG
  5 PROP                                             20   PIC OVR REL GBL   SHR NOEXE   RD   WRT LONG

    Total Space Allocated                           284

ENTRY POINTS

    Address   Type  Name

  0-00000000        XTERMS

VARIABLES

    Address   Type  Name                Address   Type  Name                Address   Type  Name                Address   Type  Name

  5-00000008  R*4   AEAD              4-00000010  R*4   B                 4-00000014  R*4   CB                4-00000028  R*4   CMID
  4-00000024  R*4   CWP               4-0000002C  R*4   DEPTH            AP-0000001B@ R*4   FRN               3-00000004  R*4   GRAV
 AP-00000010@ R*4   KT                3-0000000C  R*4   KVIS              4-00000020  R*4   LCB               4-00000008  R*4   LPP
  4-0000000C  R*4   LWL               4-00000018  R*4   M                 4-0000001C  R*4   META             AP-00000024@ R*4   MX
 AP-00000004@ R*4   MY                5-00000004  I*4   NBLADE           AP-00000028@ R*4   NPROP             5-00000000  R*4   PDIA
  5-0000000C  R*4   PDRAT             3-00000008  R*4   PI               AP-0000001C@ R*4   RANGLE            3-00000000  R*4   RHO
  4-00000000  R*4   TAFT             AP-00000014@ R*4   TFRAC             4-00000004  R*4   TFWD             AP-00000020@ R*4   VINIT
  5-00000010  R*4   XPROPR           AP-0000000C@ R*4   XRES             AP-0000002C@ R*4   XSUM                   **     R*4   XTERM1
```

```
      **      R*4  XTERM2              **      R*4  XTERM3              **      R*4  XTERM4              **      R*4  XTERM5
      **      R*4  XTERM6

ARRAYS

    Address  Type  Name                 Bytes  Dimensions

 AP-00000008@ R*4  Y                       40  (10)

FUNCTIONS AND SUBROUTINES REFERENCED

  Type  Name

   R*4  MTH$SIN
```

```
C
C
C************************************************************************
C
C
C                                SUBROUTINE YTERMS
C
C
C************************************************************************
C
C
      SUBROUTINE YTERMS(MY,T,Y,MX,FRN,AH,RANGLE,YV,YR,YVR,YVV,YRR,YSUM,
     &                  YTERM2,YTERM3)
C
C
C THIS SUBROUTINE CALCULATES THE TERMS USED IN THE DIFFERENTIAL EQUATION
C FOR DETERMINING THE Y-ACCELERATION, AND ADDS THEM BEFORE RETURNING TO
C THE MAIN PROGRAM.
C
C INPUT VARIABLES ARE:
C
C                 1) MY       - Added mass in the y-direction (kg).
C
C                 2) T        - Mean draft of the ship (meters).
C
C                 3) Y        - Vector containing the current values of the
C                               dependent variables used in the equations of
C                               motion.
C
C                 4) MX       - Added mass in the x-direction (kg).
C
C                 5) FRN      - Current value of the rudder normal force (Newtons).
C
C                 6) AH       - Coefficient used to calculate the component of the
C                               rudder force in the y-direction.
C
C                 7) RANGLE   - Current value of the rudder angle (radians).
C
C                 8) YV, YR,  - Non-dimensional hydrodynamic derivatives of the
C                    YVR, YVV,  lateral force acting on the ship.
C                    YRR
C THE OUTPUT VARIABLES ARE:
C
C                 1) YSUM     - Current value of the local y-acceleration of
C                               the ship (m/sec**2).
C
C                 2) YTERM2   - Value of the hydrodynamic lateral force acting
C                               on the ship during the manoeuvre (Newtons).
C
C                 3) YTERM3   - Influence of roll on the lateral hydrodynamic
C                               force (Newtons).
C
C DIMENSION VARIABLES
C
      DIMENSION Y(10)
C
```

```
C COMMON BLOCKS OF DATA
C
      COMMON /CONST/ RHO,GRAV,PI,KVIS
      COMMON /SHIP/ TAFT,TFWD,LPP,LWL,B,CB,M,META,LCB,CWP,CMID,DEPTH
C
C DECLARE VARIABLES
C
      REAL MY,MX,KVIS,LPP,LWL,M,META,LCB
C
C CALCULATE TERMS FOR THE Y-ACCELERATION EQUATION  (NOTE: YTERM2 IS
C SUB-DIVIDED INTO COMPONENTS YTERM21,YTERM22,ETC.)
C
      VSHIP = SQRT(Y(1)**2.+Y(3)**2.)
      YTERM1=-(M+MX)*Y(1)*Y(5)
      YTERM21=YV*Y(3)/VSHIP
      YTERM22=YR*Y(5)*LPP/VSHIP
      YTERM23=YVV*Y(3)*ABS(Y(3))/VSHIP**2.
      YTERM24=YVR*(Y(3)/VSHIP)*ABS(Y(5)*LPP/VSHIP)
      YTERM25=YRR*Y(5)*ABS(Y(5))*LPP**2./VSHIP**2.
      YTERM26=0.5*RHO*LPP*T*VSHIP**2.
      YTERM2=YTERM26*(YTERM21+YTERM22+YTERM23+YTERM24+YTERM25)
      YTERM3=0.
      YTERM4=-(1.+AH)*FRN*COS(RANGLE)
      YTERM5=M+MY
C
C SUMMATION OF TERMS
C
      YSUM=(YTERM1+YTERM2+YTERM3+YTERM4)/YTERM5
C
C RETURN TO MAIN PROGRAM
C
      RETURN
      END
```

```
YTERMS                                                             28-Sep-1988 09:07:22    VAX FORTRAN V4.7-271                   Page  57
                                                                   28-Sep-1988 09:06:26    DUA1:[LANTOS]MANOEUVRE.FOR;1

PROGRAM SECTIONS

    Name                                      Bytes   Attributes

  0 $CODE                                       273   PIC CON REL LCL   SHR   EXE   RD NOWRT LONG
  2 $LOCAL                                       20   PIC CON REL LCL NOSHR NOEXE   RD   WRT LONG
  3 CONST                                        16   PIC OVR REL GBL   SHR NOEXE   RD   WRT LONG
  4 SHIP                                         48   PIC OVR REL GBL   SHR NOEXE   RD   WRT LONG

    Total Space Allocated                       357

ENTRY POINTS

    Address   Type  Name

  0-00000000        YTERMS

VARIABLES

    Address   Type  Name                  Address   Type  Name                   Address   Type  Name                   Address   Type  Name

 AP-00000018@ R*4   AH              4-00000010  R*4   B                 4-00000014  R*4   CB                4-00000028  R*4   CMID
  4-00000024  R*4   CWP             4-0000002C  R*4   DEPTH          AP-00000014@ R*4   FRN               3-00000004  R*4   GRAV
  3-0000000C  R*4   KVIS            4-00000020  R*4   LCB             4-00000008  R*4   LPP               4-0000000C  R*4   LWL
  4-00000018  R*4   M               4-0000001C  R*4   META           AP-00000010@ R*4   MX             AP-00000004@ R*4   MY
  3-00000008  R*4   PI           AP-0000001C@ R*4   RANGLE          3-00000000  R*4   RHO            AP-00000008@ R*4   T
  4-00000000  R*4   TAFT            4-00000004  R*4   TFWD                **      R*4   VSHIP          AP-00000024@ R*4   YR
 AP-00000030@ R*4   YRR          AP-00000034@ R*4   YSUM                **      R*4   YTERM1         AP-00000038@ R*4   YTERM2
      **      R*4   YTERM21            **       R*4   YTERM22             **      R*4   YTERM23            **      R*4   YTERM24
      **      R*4   YTERM25            **       R*4   YTERM26        AP-0000003C@ R*4   YTERM3             **      R*4   YTERM4
      **      R*4   YTERM5       AP-00000020@ R*4   YV             AP-00000028@ R*4   YVR            AP-0000002C@ R*4   YVV

ARRAYS

    Address   Type  Name                Bytes  Dimensions

 AP-0000000C@ R*4   Y                      40  (10)

FUNCTIONS AND SUBROUTINES REFERENCED

  Type  Name              Type  Name

   R*4  MTH$COS            R*4  MTH$SQRT
```

```
C
C
C*******************************************************************************
C
C
C                             SUBROUTINE YAWTM
C
C
C*******************************************************************************
C
C
      SUBROUTINE YAWTM(T,Y,YTERM2,YTERM3,XMID,NVPHI,NRPHI,NPHI,NV,NR
     &                  ,NVVR,NVRR,NRR,AH,FRN,RANGLE,IZZ,JZZ,NSUM)
C
C
C THIS SUBROUTINE CALCULATES AND ADDS THE TERMS USED IN THE DIFFERENTIAL
C EQUATION FOR YAW ACCELERATION.
C
C INPUT VARIABLES ARE:
C
C               1) T          - Mean draft of the ship (meters).
C
C               2) Y          - Vector containing current values of the
C                               dependent variables of the equations of
C                               motion.
C
C               3) YTERM2     - Hydrodynamic lateral force acting on the
C                               hull (Newtons).
C
C               4) YTERM3     - Influence of roll on the lateral hydrodynamic
C                               force (Newtons).
C
C               5) XMID       - Location of midships with respect to the ship's
C                               center of gravity (meters).
C
C               6) NVPHI,     - Non-dimensional, hydrodynamic derivatives of yaw
C                  NRPHI,NPHI,  moment.
C                  NV,NR,NVVR,
C                  NRR,NVRR
C
C               7) AH         - Coefficient used to calculate the yaw moment due
C                               to the rudder force.
C
C               8) FRN        - Current value of rudder normal force (Newtons).
C
C               9) RANGLE     - Current value of the rudder angle (radians).
C
C              10) IZZ        - Mass moment of inertia about the vertical
C                               z-axis (kg-m**2).
C
C              11) JZZ        - Added mass moment of inertia about the vertical
C                               z-axis (kg-m**2).
C
C THE OUTPUT VARIABLE IS:
C
C               1) NSUM       - Current value of yaw acceleration (rad./sec.**2).
C
```

```
C
C DIMENSION VARIABLES
C
      DIMENSION Y(10)
C
C COMMON BLOCKS OF DATA
C
      COMMON /CONST/ RHO,GRAV,PI,KVIS
      COMMON /SHIP/ TAFT,TFWD,LPP,LWL,B,CB,M,META,LCB,CWP,CMID,DEPTH
      COMMON /RUDR/ HRUD,ARUD,XR,ZR
C
C DECLARE VARIABLES
C
      REAL NV,NVVR,NVRR,NR,NRR,NVPHI,NRPHI,NPHI,NSUM,IZZ,JZZ
      REAL KVIS,LPP,LWL,M,META,LCB
C
C CALCULATE TERMS FOR YAW ACCELERATION  (NOTE: NTERM1 AND NTERM2 ARE
C SUBDIVIDED INTO COMPONENTS NTRM11,NTRM12,ETC.)
C
      VSHIP=SQRT(Y(1)**2.+Y(3)**2.)
      TRM11=0.5*RHO*T*(VSHIP**2.)*(LPP**2.)
      TRM12=NV*Y(3)/VSHIP
      TRM13=NR*Y(5)*LPP/VSHIP
      TRM14=NVVR*((Y(3)/VSHIP)**2.)*Y(5)*LPP/VSHIP
      TRM15=NVRR*(Y(3)/VSHIP)*(Y(5)*LPP/VSHIP)**2.
      TRM16=NRR*(Y(5)*LPP/VSHIP)*ABS(Y(5)*LPP/VSHIP)
      TERM1=TRM11*(TRM12+TRM13+TRM14+TRM15+TRM16)
C
      TRM21=NPHI*Y(8)
      TRM22=NVPHI*Y(3)/VSHIP*ABS(Y(8))
      TRM23=NRPHI*Y(5)*LPP/VSHIP*ABS(Y(8))
      TERM2=TRM11*(TRM21+TRM22+TRM23)
C
      TERM3=(YTERM2+YTERM3)*XMID
      TERM4=-(1.+AH)*XR*FRN*COS(RANGLE)
      TERM5=IZZ+JZZ
C
C SUMMATION OF TERMS
C
      NSUM=(TERM1+TERM2+TERM3+TERM4)/TERM5
C
C RETURN TO MAIN PROGRAM
C
      RETURN
      END
```

```
PROGRAM SECTIONS

    Name                                    Bytes   Attributes

  0 $CODE                                     303   PIC CON REL LCL   SHR   EXE    RD NOWRT LONG
  2 $LOCAL.                                    20   PIC CON REL LCL NOSHR NOEXE    RD   WRT LONG
  3 CONST                                      16   PIC OVR REL GBL   SHR NOEXE    RD   WRT LONG
  4 SHIP                                       48   PIC OVR REL GBL   SHR NOEXE    RD   WRT LONG
  5 RUDR                                       16   PIC OVR REL GBL   SHR NOEXE    RD   WRT LONG

    Total Space Allocated                     403

ENTRY POINTS

    Address  Type  Name

  0-00000000       YAWTM

VARIABLES

    Address  Type  Name               Address  Type  Name               Address  Type  Name               Address  Type  Name

AP-00000038@ R*4   AH              5-00000004  R*4   ARUD            4-00000010  R*4   B               4-00000014  R*4   CB
 4-00000028  R*4   CMID            4-00000024  R*4   CWP             4-0000002C  R*4   DEPTH        AP-0000003C@ R*4   FRN
 3-00000004  R*4   GRAV            5-00000000  R*4   HRUD         AP-00000044@ R*4   IZZ          AP-00000048@ R*4   JZZ
 3-0000000C  R*4   KVIS            4-00000020  R*4   LCB             4-00000008  R*4   LPP             4-0000000C  R*4   LWL
 4-00000018  R*4   M               4-0000001C  R*4   META         AP-00000020@ R*4   NPHI         AP-00000028@ R*4   NR
AP-0000001C@ R*4   NRPHI        AP-00000034@ R*4   NRR          AP-0000004C@ R*4   NSUM         AP-00000024@ R*4   NV
AP-00000018@ R*4   NVPHI        AP-00000030@ R*4   NVRR         AP-0000002C@ R*4   NVVR            3-00000008  R*4   PI
AP-00000040@ R*4   RANGLE          3-00000000  R*4   RHO          AP-00000004@ R*4   T               4-00000000  R*4   TAFT
         **  R*4   TERM1                   **  R*4   TERM2                **  R*4   TERM3                   **  R*4   TERM4
         **  R*4   TERM5           4-00000004  R*4   TFWD                 **  R*4   TRM11                   **  R*4   TRM12
         **  H*4   TRM13                   **  R*4   TRM14                **  R*4   TRM15                   **  R*4   TRM16
         **  R*4   TRM21                   **  R*4   TRM22                **  R*4   TRM23                   **  R*4   VSHIP
AP-00000014@ R*4   XMID            5-00000008  R*4   XR           AP-0000000C@ R*4   YTERM2       AP-00000010@ R*4   YTERM3
 5-0000000C  R*4   ZR

ARRAYS

    Address  Type  Name                Bytes  Dimensions

AP-00000008@ R*4   Y                      40  (10)

FUNCTIONS AND SUBROUTINES REFERENCED

  Type  Name            Type  Name

  R*4   MTH$COS         R*4   MTH$SQRT
```

```
C
C
C***********************************************************************
C
C
C                         SUBROUTINE ROLL
C
C
C***********************************************************************
C
C
      SUBROUTINE ROLL(SPRING, DAMP, Y, F, YTERM2, YTERM3, ZH, AH, IXX, JXX,
     &                RANGLE, FRN, RSUM)
C
C
C THIS SUBROUTINE CALCULATES AND ADDS THE TERMS USED IN THE DIFFERENTIAL
C EQUATION FOR ROLL ACCELERATION.
C
C INPUT VARIABLES ARE:
C
C              1) SPRING - Roll restoring moment coefficient (N-m).
C
C              2) DAMP   - Roll damping coefficient (kg-m**2/sec).
C
C              3) Y      - Vector containing current values of the dependent
C                          variables used in the equations of motion.
C
C              4) F      - Vector containing current values of the derivatives
C                          of the dependent variables used in the equations of
C                          motion.
C
C              5) YTERM2 - Hydrodynamic lateral force acting on ship (Newtons).
C
C              6) YTERM3 - Influence of roll on the lateral force (Newtons).
C
C              7) ZH     - The z-coordinate of the center of gravity of the
C                          ship's underwater profile area (meters).
C
C              8) AH     - Coefficient used to calculate the roll moment due to
C                          due to the rudder force.
C
C              9) IXX    - Mass moment of inertia about the longitudinal x-axis
C                          (kg-m**2).
C
C             10) JXX    - Added mass moment of inertia about the longitudinal
C                          x-axis (kg-m**2).
C
C             11) RANGLE - Current rudder angle (radians).
C
C             12) FRN    - Current rudder normal force (Newtons).
C
C OUTPUT VARIABLE IS:
C
C              1) RSUM   - Value of roll acceleration (rad./sec**2).
C
C
C DIMENSION VARIABLES
```

```
C
      DIMENSION Y(10),F(10)
C
C COMMON BLOCKS OF DATA
C
      COMMON /CONST/ RHO,GRAV,PI,KVIS
      COMMON /SHIP/ TAFT,TFWD,LPP,LWL,B,CB,M,META,LCB,CWP,CMID,DEPTH
      COMMON /RUDR/ HRUD,ARUD,XR,ZR
C
C DECLARE VARIABLES
C
      REAL IXX,JXX,KVIS,LPP,LWL,M,META,LCB,MY,MX
C
C CALCULATE TERMS FOR ROLL ACCELERATION
C
      ROLL1=DAMP*Y(7)
      ROLL2=SPRING*Y(8)
      ROLL3=-(-MY*F(3)-MX*Y(1)*Y(5)+YTERM2+YTERM3)*ZH
      ROLL4=(1.+AH)*ZR*FRN*COS(RANGLE)
      ROLL5=IXX+JXX
C
C SUMMATION OF ALL TERMS
C
      RSUM=(ROLL1+ROLL2+ROLL3+ROLL4)/ROLL5
C
C RETURN TO MAIN PROGRAM
C
      RETURN
      END
```

```
PROGRAM SECTIONS

    Name                               Bytes   Attributes

  0 $CODE                               135    PIC CON REL LCL   SHR   EXE   RD NOWRT LONG
  2 $LOCAL                               48    PIC CON REL LCL NOSHR NOEXE   RD   WRT LONG
  3 CONST                                16    PIC OVR REL GBL   SHR NOEXE   RD   WRT LONG
  4 SHIP                                 48    PIC OVR REL GBL   SHR NOEXE   RD   WRT LONG
  5 RUDR                                 16    PIC OVR REL GBL   SHR NOEXE   RD   WRT LONG

    Total Space Allocated               263

ENTRY POINTS

    Address   Type  Name

  0-00000000        ROLL

VARIABLES

    Address   Type  Name              Address   Type  Name              Address   Type  Name              Address   Type  Name

 AP-00000020@ R*4   AH             5-00000004   R*4   ARUD           4-00000010   R*4   B              4-00000014   R*4   CB
  4-00000028  R*4   CMID           4-00000024   R*4   CWP         AP-00000008@  R*4   DAMP           4-0000002C   R*4   DEPTH
 AP-00000030@ R*4   FRN            3-00000004   R*4   GRAV           5-00000000   R*4   HRUD        AP-00000024@  R*4   IXX
 AP-00000028@ R*4   JXX            3-0000000C   R*4   KVIS           4-00000020   R*4   LCB            4-00000008   R*4   LPP
  4-0000000C  R*4   LWL            4-00000018   R*4   M              4-0000001C   R*4   META           2-00000004   R*4   MX
  2-00000000  R*4   MY             3-00000008   R*4   PI          AP-0000002C@  R*4   RANGLE         3-00000000   R*4   RHO
      **      R*4   ROLL1               **      R*4   ROLL2              **       R*4   ROLL3              **       R*4   ROLL4
      **      R*4   ROLL5       AP-00000034@  R*4   RSUM        AP-00000004@  R*4   SPRING         4-00000000   R*4   TAFT
  4-00000004  R*4   TFWD           5-00000008   R*4   XR          AP-00000014@  R*4   YTERM2      AP-00000018@  R*4   YTERM3
 AP-0000001C@ R*4   ZH             5-0000000C   R*4   ZR

ARRAYS

    Address   Type  Name              Bytes  Dimensions

 AP-00000010@ R*4   F                    40  (10)
 AP-0000000C@ R*4   Y                    40  (10)

FUNCTIONS AND SUBROUTINES REFERENCED

  Type  Name

   R*4  MTH$COS
```

```
C
C
C***********************************************************************
C
C
C                           SUBROUTINE PROPR
C
C
C***********************************************************************
C
C
      SUBROUTINE PROPR(IPP,Y,KG,SHP,IGP,ENGTYP,PRPSUM)
C
C THIS SUBROUTINE CALCULATES AND ADDS THE TERMS USED IN THE DIFFERENTIAL
C EQUATION FOR DETERMINING ACCELERATION OF THE PROPELLER.
C
C INPUT VARIABLES ARE:
C
C              1) IPP    - Virtual mass moment of inertia of the propeller,
C                          includes the added mass (kg-m**2).
C
C              2) Y      - Vector containing current values of the dependent
C                          variables used in the equations of motion.
C
C              3) KG     - Propeller torque coefficient.
C
C              4) SHP    - Shaft horsepower (kilowatts).
C
C              5) IGP    - Counter to indicate when to initialize the engine
C                          torque in the propeller equation.
C
C              6) ENGTYP - Constant indicating type of propulsion plant.
C
C                                   ENGTYP=1 - STEAM TURBINE
C                                   ENGTYP=2 - SLOW SPEED DIESEL
C
C OUTPUT VARIABLE IS:
C
C              1) PRPSUM - Value of propeller acceleration (rev/sec**2).
C
C
C DIMENSION VARIABLES
C
       DIMENSION Y(10),F(10)
C
C COMMON BLOCKS OF DATA
C
       COMMON /CONST/ RHO,GRAV,PI,KVIS
       COMMON /SHIP/ TAFT,TFWD,LPP,LWL,B,CB,M,META,LCB,CWP,CMID,DEPTH
       COMMON /PROP/ PDIA,NBLADE,AEAO,PDRAT,XPROPR
C
C DECLARE VARIABLES
C
       REAL IPP,KG,KVIS,LPP,LWL,M,META,LCB
       INTEGER ENGTYP
C
C CALCULATE TERMS FOR PROPELLER ACCELERATION
```

```
0058      C
0059            IGP=IGP+1
0060            PROP1=-RHO*Y(9)**2.*PDIA**5.*KQ
0061            IF (IGP .EQ. 1) THEN
0062                PROP2=ABS(PROP1)
0063            END IF
0064            IF (ENGTYP .EQ. 1) THEN
0065                PROP2=SHP/(2.*PI*Y(9))
0066            END IF
0067            PROP3=2.*PI*IPP
0068      C
0069      C SUMMATION OF ALL TERMS
0070      C
0071            PRPSUM=(PROP1+PROP2)/PROP3
0072      C
0073      C RETURN TO MAIN PROGRAM
0074      C
0075            RETURN
0076            END


PROGRAM SECTIONS

    Name                                   Bytes   Attributes

  0 $CODE                                    117   PIC CON REL LCL   SHR    EXE   RD NOWRT LONG
  2 $LOCAL                                    64   PIC CON REL LCL NOSHR  NOEXE  RD   WRT LONG
  3 CONST                                     16   PIC OVR REL GBL   SHR  NOEXE  RD   WRT LONG
  4 SHIP                                      48   PIC OVR REL GBL   SHR  NOEXE  RD   WRT LONG
  5 PROP                                      20   PIC OVR REL GBL   SHR  NOEXE  RD   WRT LONG

    Total Space Allocated                    265

ENTRY POINTS

    Address   Type  Name

  0-00000000        PROPR

VARIABLES

    Address   Type  Name             Address   Type  Name             Address   Type  Name             Address   Type  Name

  5-00000008  R*4   AEAO           4-00000010  R*4   B              4-00000014  R*4   CB             4-00000028  R*4   CMID
  4-00000024  R*4   CWP            4-0000002C  R*4   DEPTH         AP-00000018@ I*4   ENGTYP         3-00000004  R*4   GRAV
 AP-00000004@ R*4   IPP           AP-00000014@ I*4   IGP           AP-0000000C@ R*4   KQ             3-0000000C  R*4   KVIS
  4-00000020  R*4   LCB            4-00000008  R*4   LPP            4-0000000C  R*4   LWL            4-00000018  R*4   M
  4-0000001C  R*4   META           5-00000004  I*4   NBLADE         5-00000000  R*4   PDIA           5-0000000C  R*4   PDRAT
  3-00000008  R*4   PI                 **      R*4   PROP1          2-00000028  R*4   PROP2              **      R*4   PROP3
 AP-0000001C@ R*4   PRPSUM         3-00000000  R*4   RHO           AP-00000010@ R*4   SHP            4-00000000  R*4   TAFT
  4-00000004  R*4   TFWD           5-00000010  R*4   XPROPR
```

```
ARRAYS

    Address   Type  Name                         Bytes  Dimensions

  2-00000000  R*4   F                              40   (10)
 AP-00000008@ R*4   Y                              40   (10)
```

```
C
C
C***********************************************************************
C
C
C                              SUBROUTINE INTERP
C
C
C***********************************************************************
C
C
      SUBROUTINE INTERP(XARRAY, YARRAY, XVAL, ITR, YVAL)
C
C
C THIS SUBROUTINE DETERMINES THE VALUE OF A FUNCTION AT A SPECIFIC
C POINT, BY INTERPOLATING BETWEEN TWO KNOWN VALUES OF THE FUNCTION.
C
C INPUT VARIABLES ARE:
C
C              1) XARRAY - 'X' values at which the function can be
C                          evaluated. They must be given in either
C                          ascending of descending order.
C
C              2) YARRAY - 'Y' values of the function corresponding to
C                          the 'X' values.  There must be a one-to-one
C                          correspondence between the 'XARRAY' and the
C                          'YARRAY'.
C
C              3) XVAL   - The value of the independent variable at
C                          which the function is to be evaluated. (Eg.
C                          in this program XVAL=initial manoeuvring speed).
C
C              4) ITR    - The number of values in 'XARRAY' and 'YARRAY'.
C
C OUTPUT VARIABLE IS:
C
C              1) YVAL   - Interpolated value of the function at the
C                          required 'XVAL'.  (Eg. In this program YVAL=
C                          ship resistance at the initial manoeuvring speed).
C
C DECLARE/DIMENSION VARIABLES
C
      DIMENSION XARRAY(ITR), YARRAY(ITR)
C
C INITIALIZE VARIABLES
C
      YVAL = 0.
      I=0
      ITEST=0
C
C LOCATE THE VALUES OF XARRAY THAT SURROUND THE VALUE 'XVAL'
C
      DO 11 WHILE((I .LE. ITR) .AND. (ITEST .EQ. 0))
         I=I+1
         IF (XVAL .EQ. XARRAY(I)) THEN
            YVAL=YARRAY(I)
            ITEST=1
         END IF
   11 CONTINUE
      I=0
      IF (ITEST .EQ. 0) THEN
           DO 22 WHILE((I .LT. ITR) .AND. (ITEST .EQ. 0))
              I=I+1
              IF ((XARRAY(I) .LT. XVAL) .AND.
     &            (XARRAY(I+1) .GT. XVAL)) THEN
                   XONE=XARRAY(I)
                   XTWO=XARRAY(I+1)
                   YONE=YARRAY(I)
                   YTWO=YARRAY(I+1)
                   ITEST=2
              ELSE IF((XARRAY(I) .GT. XVAL) .AND.
     &               (XARRAY(I+1) .LT. XVAL)) THEN
                   XONE=XARRAY(I)
                   XTWO=XARRAY(I+1)
                   YONE=YARRAY(I)
                   YTWO=YARRAY(I+1)
                   ITEST=2
              END IF
   22      CONTINUE
      END IF
      IF (ITEST .EQ. 2) THEN
           YVAL=YTWO-(XTWO-XVAL)*(YTWO-YONE)/(XTWO-XONE)
      END IF
C
C RETURN TO MAIN PROGRAM
C
      RETURN
      END
```

```
PROGRAM SECTIONS

    Name                                   Bytes   Attributes

  0 $CODE                                    257   PIC CON REL LCL   SHR   EXE   RD NOWRT LONG
  2 $LOCAL                                    96   PIC CON REL LCL NOSHR NOEXE   RD   WRT LONG

    Total Space Allocated                    353

ENTRY POINTS

    Address   Type  Name

  0-00000000        INTERP

VARIABLES

    Address   Type  Name                Address   Type  Name                 Address   Type  Name                Address   Type  Name

       **      I*4  I                      **      I*4  ITEST            AP-00000010@ I*4  ITR              2-00000000   R*4  XONE
  2-00000004   R*4  XTWO          AP-0000000C@ R*4  XVAL               2-00000008   R*4  YONE             2-0000000C   R*4  YTWO
 AP-00000014@ R*4  YVAL

ARRAYS

    Address   Type  Name                  Bytes  Dimensions

 AP-00000004@ R*4  XARRAY                   **  (*)
 AP-00000008@ R*4  YARRAY                   **  (*)

LABELS

    Address   Label       Address    Label

       **      11           **       22
```

```
C
C
C***********************************************************************
C
C
C                              SUBROUTINE CIRCLE
C
C
C***********************************************************************
C
C
      SUBROUTINE CIRCLE(TAU,ORDANG,ASUB,LAMDA,VX1,NPROP,NSTERN,NRUDR,TDES
     &                  ,T,VST,ADV,TR,TACDIA,STDYDIA,IERROR)
C
C
C THIS SUBROUTINE CALCULATES THE TURNING CIRCLE CHARACTERISTICS OF A SHIP
C USING EMPIRICAL RELATIONSHIPS DERIVED IN REFERENCE 3 OF THE MAIN REPORT
C
C THE FOLLOWING ESTIMATES ARE MADE FOR EITHER A SINGLE SCREW SHIP, OR A TWIN
C SCREW SHIP.
C
C                       1) TACTICAL DIAMETER
C                       2) STEADY TURNING DIAMETER
C                       3) ADVANCE
C                       4) TRANSFER
C                       5) STEADY TURNING SPEED
C
C
C THE INPUT VARIABLES ARE:
C
C               1) TAU          - Trim of ship [meters] (-ve if trim by bow, and +ve
C                                 if trim by stern). This parameter is calculated
C                                 in SUBROUTINE CONSTN.
C
C               2) ORDANG       - Ordered rudder angle [degrees] at the start of
C                                 the turning manoeuvre.  This is one of the
C                                 original input parameters.
C
C               3) ASUB         - Submerged bow profile area [m**2], which is the
C                                 area below the waterline and forward of the fore
C                                 perpendicular.  For a ship with a bulbous bow,
C                                 the area is +ve, and for a conventional raked
C                                 bow the area is -ve.
C
C               4) LAMDA        - Rudder aspect ratio.  One of the original input
C                                 parameters.
C
C               5) VX1          - Initial speed (m/s) of the vessel at the start of
C                                 the manoeuvre.  It is an initial input parameter.
C
C               6) NPROP        - Number of propellers fitted to the ship.
C
C               7) NSTERN       - Type of stern configuration on the vessel.
C                                       1 = closed stern
C                                       2 = open water stern
C
C               8) NRUDR        - Number of rudders fitted to the ship.
```

```
C
C               9) TDES         - Design draft [meters].
C
C              10) T            - Mean draft [meters] at time of trials.
C
C OUTPUT VARIABLES ARE:
C
C               1) VST          - Steady turning speed [knots].
C
C               2) ADV          - Advance of ship during manoeuvre [meters].
C
C               3) TR           - Transfer of ship during manoeuvre [meters].
C
C               4) TACDIA       - Tactical diameter [meters].
C
C               5) STDYDIA      - Steady turning diameter [meters].
C
C               6) IERROR       - Flag indicating if one of the input variables
C                                 is outside the range of the database.
C
C COMMON BLOCKS OF MATERIAL
C
      COMMON /SHIP/ TAFT,TFWD,LPP,LWL,B,CB,M,META,LCB,CWP,CMID,DEPTH
      COMMON /RUDR/ HRUD,ARUD,XR,ZR
C
C DIMENSION/DECLARE VARIABLES
C
      DIMENSION IERROR(9)
C
      REAL LPP,LWL,M,META,LCB,LAMDA,NPROP
C
C CHANGE SIGN OF RUDDER ANGLE BECAUSE THE CONVENTION USED IN THIS ROUTINE
C IS OPPOSITE TO THE REST OF THE PROGRAM.
C
      ORDANG=-ORDANG
C
C ASSIGN A VALUE TO 'TDES' IF IT WAS ORIGINALLY INPUT AS 0.
C
      IF (TDES .EQ. 0.) THEN
        TDES=T
      END IF
C
      IF (NPROP .EQ. 1.) THEN
C
C CALCULATE TURNING CIRCLE PARAMETERS FOR SINGLE SCREW SHIPS
C
C STEADY TURNING DIAMETER
C
            STD1=4.19-203.*CB/ORDANG
            STD2=(47.4*TAU/LPP)-(13.*B/LPP)
            STD3=194./ORDANG
            STD4=35.8*((HRUD**2./LAMDA)/(LPP*T))*(NSTERN-1)
            STD5=3.82*((HRUD**2./LAMDA)/(LPP*T))*(NSTERN-2)
            STD6=7.79*ASUB/(LPP*T)
            STD7=0.7*((T/TDES)-1.)*(ORDANG/ABS(ORDANG))*(NSTERN-1)
            STDYDIA=(STD1+STD2+STD3-STD4+STD5+STD6+STD7)*LPP
C
```

```
C TACTICAL DIAMETER
C
          TDIA1=0.91*STDYDIA/LPP
          TDIA2=0.424*(VX1/0.51444)/SQRT(LPP*3.28)
          TACDIA=(TDIA1+TDIA2+0.675)*LPP
C
C ADVANCE
C
          ADV=(0.319*TACDIA/LPP+1.33)*LPP
C
C TRANSFER
C
          TR=(0.497*TACDIA/LPP-0.065)*LPP
C
C STEADY TURNING SPEED
C
          VST=(0.074*TACDIA/LPP+0.149)*(VX1/0.51444)
C
        ELSE
C
C TURNING CIRCLE PARAMETERS FOR TWIN SCREW SHIP
C
C STEADY TURNING DIAMETER
C
          STD1=0.727-197.*CB/ABS(ORDANG)
          STD2=(4.65*B/LPP)+(41.*TAU/LPP)+(188./ABS(ORDANG))
          STD3=218.*((HRUD**2./LAMDA)/(LPP*T))*(NRUDR-1)
          STD4=3.2*(VX1/0.51444)/SQRT(LPP*3.28)
          STD5=25.56*ASUB/(LPP*T)
          STDYDIA=(STD1+STD2-STD3+STD4+STD5)*LPP
C
C TACTICAL DIAMETER
C
          TACDIA=(0.14+STDYDIA/LPP)*LPP
C
C ADVANCE
C
          ADV=(1.1+0.514*TACDIA/LPP)*LPP
C
C TRANSFER
C
          TR=(0.531*TACDIA/LPP-0.357)*LPP
C
C STEADY TURNING SPEED
C
          VST=(0.543+0.028*TACDIA/LPP)*(VX1/0.51444)
C
     END IF
C
C PERFORM A DATA CHECK TO DETERMINE IF ANY OF THE INPUT VALUES ARE
C OUTSIDE THE RANGE OF THE DATABASE.  (NOTE: IF SOME OF THE PARAMETERS ARE
C NOT WITHIN THE LIMITS OF THE DATABASE, THEN A MESSAGE WILL BE APPENDED TO
C THE OUTPUT INDICATING THAT THE STANDARD DEVIATIONS MAY NOT BE MEANINGFUL.)
C
     IF (NPROP .EQ. 1.) THEN
          IF ((LPP .LT. 55.) .OR. (LPP .GT. 330.)) THEN
              IERROR(1)=1
          END IF
          IF ((CB .LT. .56) .OR. (CB .GT. .87)) THEN
             IERROR(2)=1
          END IF
          IF ((ABS(ORDANG) .LT. 10.) .OR. (ABS(ORDANG) .GT. 45.)) THEN
             IERROR(3)=1
          END IF
          IF (((B/LPP) .LT. .11) .OR. ((B/LPP) .GT. .18)) THEN
             IERROR(4)=1
          END IF
          IF (((TAU/LPP) .LT. 0.) .OR. ((TAU/LPP) .GT. .05)) THEN
             IERROR(5)=1
          END IF
          IF ((((HRUD**2./LAMDA)/(LPP*T)) .LT. .01) .OR.
     &        (((HRUD**2./LAMDA)/(LPP*T)) .GT. .04)) THEN
             IERROR(6)=1
          END IF
          IF (((ASUB/(LPP*T)) .LT. -0.11) .OR.
     &        ((ASUB/(LPP*T)) .GT. 0.04)) THEN
             IERROR(7)=1
          END IF
          IF ((((VX1/.51444)/SQRT(LPP*3.28)) .LT. 0.2) .OR.
     &        (((VX1/.51444)/SQRT(LPP*3.28)) .GT. 1.0)) THEN
             IERROR(8)=1
          END IF
          IF (((T/TDES) .LT. .5) .OR. ((T/TDES) .GT. 1.)) THEN
             IERROR(9)=1
          END IF
        ELSE
          IF ((LPP .LT. 75.) .OR. (LPP .GT. 225.)) THEN
             IERROR(1)=1
          END IF
          IF ((CB .LT. .42) .OR. (CB .GT. .62)) THEN
             IERROR(2)=1
          END IF
          IF ((ABS(ORDANG) .LT. 10.) .OR. (ABS(ORDANG) .GT. 35.)) THEN
             IERROR(3)=1
          END IF
          IF (((B/LPP) .LT. .06) .OR. ((B/LPP) .GT. .20)) THEN
             IERROR(4)=1
          END IF
          IF (((TAU/LPP) .LT. -0.01) .OR. ((TAU/LPP) .GT. .03)) THEN
             IERROR(5)=1
          END IF
          IF ((((HRUD**2./LAMDA)/(LPP*T)) .LT. .01) .OR.
     &        (((HRUD**2./LAMDA)/(LPP*T)) .GT. .02)) THEN
             IERROR(6)=1
          END IF
          IF (((ASUB/(LPP*T)) .LT. -0.10) .OR.
     &        ((ASUB/(LPP*T)) .GT. 0.0)) THEN
             IERROR(7)=1
          END IF
          IF ((((VX1/.51444)/SQRT(LPP*3.28)) .LT. 0.25) .OR.
     &        (((VX1/.51444)/SQRT(LPP*3.28)) .GT. 2.2)) THEN
             IERROR(8)=1
          END IF
          IF (((T/TDES) .LT. .6) .OR. ((T/TDES) .GT. 1.1)) THEN
```

```
0229                    IERROR(9)=1
0230                END IF
0231            END IF
0232    C
0233    C RETURN TO MAIN PROGRAM
0234    C
0235            RETURN
0236            END


PROGRAM SECTIONS

    Name                                     Bytes   Attributes

  0 $CODE                                     1267   PIC CON REL LCL   SHR   EXE   RD NOWRT LONG
  2 $LOCAL                                      24   PIC CON REL LCL NOSHR NOEXE   RD   WRT LONG
  3 SHIP                                        48   PIC OVR REL GBL   SHR NOEXE   RD   WRT LONG
  4 RUDR                                        16   PIC OVR REL GBL   SHR NOEXE   RD   WRT LONG

    Total Space Allocated                     1355

ENTRY POINTS

    Address   Type  Name

  0-00000000        CIRCLE

VARIABLES

    Address   Type  Name               Address   Type  Name               Address   Type  Name               Address   Type  Name

 AP-00000030@ R*4   ADV              4-00000004  R*4   ARUD          AP-0000000C@ R*4   ASUB             3-00000010  R*4   B
   3-00000014 R*4   CB               3-00000028  R*4   CMID            3-00000024 R*4   CWP              3-0000002C  R*4   DEPTH
   4-00000000 R*4   HRUD          AP-00000010@ R*4   LAMDA           3-00000020 R*4   LCB              3-00000008  R*4   LPP
   3-0000000C R*4   LWL              3-00000018  R*4   M               3-0000001C R*4   META          AP-00000018@ R*4   NPROP
 AP-00000020@ I*4   NRUDR         AP-0000001C@ I*4   NSTERN        AP-00000008@ R*4   ORDANG              **       R*4   STD1
       **     R*4   STD2                 **      R*4   STD3                **     R*4   STD4                 **       R*4   STD5
       **     R*4   STD6                 **      R*4   STD7          AP-0000003C@ R*4   STDYDIA       AP-00000028@ R*4   T
 AP-00000038@ R*4   TACDIA           3-00000000  R*4   TAFT          AP-00000004@ R*4   TAU           AP-00000024@ R*4   TDE
   2-00000000 R*4   TDES                 **      R*4   TDIA1               **     R*4   TDIA2            3-00000004  R*4   TFWD
 AP-00000034@ R*4   TR            AP-0000002C@ R*4   VST           AP-00000014@ R*4   VX1              4-00000008  R*4   XR
   4-0000000C R*4   ZR

ARRAYS

    Address   Type  Name                 Bytes  Dimensions

 AP-00000040@ I*4   IERROR                  36  (9)
```

```
FUNCTIONS AND SUBROUTINES REFERENCED

  Type  Name
   R*4  MTH$SQRT
```

```
C
C
C******************************************************************************
C
C
C                            SUBROUTINE CRASH
C
C
C******************************************************************************
C
C
      SUBROUTINE CRASH(VCRSH,XRES,M,THRAFT,SPD,RTOT,ITR,REACH)
C
C
C THIS SUBROUTINE ESTIMATES THE HEAD REACH OF SHIP DURING THE CRASH STOP
C MANOEUVRE.  THE EMPIRICAL FORMULA WAS DERIVED IN REFERENCE 2 OF THE MAIN
C REPORT.
C
C THE INPUT VARIABLES ARE:
C
C           1) VCRSH                 - Initial speed of the ship [m/sec] at the
C                                      start of the crash stop manoeuvre. VCRSH
C                                      must be in the range of initial resistance
C                                      prediction, if it is not equal to VX1.
C
C           2) XRES                  - Initial resistance of the ship [newtons], at
C                                      the approach speed 'VCRSH'.  If the approach
C                                      speed is not equal to the initial speed for
C                                      the other manoeuvres then a new value for
C                                      XRES will be calculated by calling the
C                                      subroutine 'INTERP'.
C
C           3) M                     - Mass of ship [kg].
C
C           4) THRAFT                - Maximum available astern thrust [newtons].
C
C           5) SPD                   - Array of speed values used in the
C                                      interpolation subroutine if required.
C
C           6) RTOT                  - Array of total resistance values used in the
C                                      interpolation subroutine if required.
C
C           7) ITR                   - Counter used to dimension the 'SPD' and 'RTOT'
C                                      arrays.
C
C THE OUTPUT VARIABLE IS:
C
C           1) REACH                 - Head reach of the ship [meters].
C
C
C DECLARE VARIABLES
C
      REAL M
C
C DIMENSION VARIABLES
C
      DIMENSION SPD(ITR),RTOT(ITR)
```

```
C
C CONVERT UNITS OF INPUT VARIABLES FOR USE IN THE PREDICTION FORMULA
C
C SPEED IN 'KNOTS'
C
      VCR=VCRSH/.51444
C
C DETERMINE IF A NEW INTERPOLATED VALUE OF RESISTANCE IS REQUIRED
C
      IF (ABS(VCRSH-VX1) .GT. .001) THEN
          CALL INTERP(SPD,RTOT,VCRSH,ITR,XRES)
      END IF
C
C RESISTANCE IN 'POUNDS'
C
      RES=XRES/4.44822
C
C DISPLACEMENT IN 'TONS'
C
      DISPL=M/1016.05
C
C ASTERN THRUST IN 'POUNDS'
C
      THRUST=THRAFT/4.44822
C
C CALCULATE HEAD REACH
C
      RCH1=(106.2*VCR**2.)/(THRUST/DISPL)
      RCH2=34.3*VCR**2.*RES/DISPL
      RCH3=(THRUST/DISPL)**2.
      RCH4=16.9*VCR
      REACH=(RCH1-(RCH2/RCH3)+RCH4)/3.28
C
C RETURN TO MAIN PROGRAM
C
      RETURN
      END
```

```
PROGRAM SECTIONS

    Name                                   Bytes   Attributes

  0 $CODE                                    198   PIC CON REL LCL   SHR   EXE   RD NOWRT LONG
  2 $LOCAL                                   108   PIC CON REL LCL NOSHR NOEXE   RD   WRT LONG

    Total Space Allocated                    306

ENTRY POINTS

    Address   Type  Name

  0-00000000        CRASH

VARIABLES

    Address   Type  Name              Address   Type  Name              Address   Type  Name              Address   Type  Name

      **      R*4   DISPL       AP-0000001C@ I*4   ITR         AP-0000000C@ R*4   M                   **      R*4   RCH1
      **      R*4   RCH2             **      R*4   RCH3             **      R*4   RCH4        AP-00000020@ R*4   REACH
      **      R*4   RES         AP-00000010@ R*4   THRAFT           **      R*4   THRUST              **      R*4   VCR
  AP-00000004@ R*4  VCRSH        2-00000000  R*4   VX1         AP-00000008@ R*4   XRES

ARRAYS

    Address   Type  Name                   Bytes  Dimensions

  AP-00000018@ R*4  RTOT                      **  (*)
  AP-00000014@ R*4  SPD                       **  (*)

FUNCTIONS AND SUBROUTINES REFERENCED

   Type  Name
         INTERP
```

```
C
C
C***********************************************************************
C
C
C                           SUBROUTINE TEST
C
C
C***********************************************************************
C
      SUBROUTINE TEST(MNVRE,ITIME,TIME,Y,YAWANG,ANGMAX,ZIGZAG,X1,Y1,
     &                WIDTH1,PERIOD1,PERIOD2,RESULTS)
C
C THIS SUBROUTINE PERFORMS A SERIES OF TESTS DURING EACH OF THE MANOEUVRES.
C THE TESTS CALCULATE THE FOLLOWING PARAMETERS:
C
C               TURNING CIRCLE MANOEUVRE
C
C                       1) ADVANCE
C                       2) TRANSFER
C                       3) TACTICAL DIAMETER
C                       4) STEADY TURNING DIAMETER
C                       5) STEADY TURNING SPEED
C
C               ZIGZAG MANOEUVRE
C
C                       1) OVERSHOOT ANGLE
C                       2) OVERSHOOT WIDTH OF PATH
C                       3) PERIOD
C                       4) REACH
C
C               SPIRAL MANOEUVRE
C
C                       (The results of the spiral manoeuvre are obtained
C                        in the subroutine RUDANG.  They are the constant
C                        turning rates at a particular rudder angle.)
C
C THE INPUT VARIABLES ARE:
C
C               1) MNVRE        - constant indicating type of manoeuvre
C                                 that is being simulated.
C
C               2) ITIME        - counter used in the subroutine.
C
C               3) TIME         - current value of time.
C
C               4) Y            - array containing current values of the
C                                 dependent variables.
C
C               5) YAWANG       - array containing all values of yaw angle
C                                 up to the current time step.
C
C               6) ANGMAX       - initial ordered rudder angle in the spiral
C                                 manoeuvre.
C
```

```
C               7) ZIGZAG       - counter for the zigzag manoeuvre, which
C                                 indicates the number of rudder executes that
C                                 have occurred.
C
C               8) X1           - initial global x-position of the ship.  Usually
C                                 equals zero (0).
C
C               9) Y1           - initial global y-position of the ship.  Usually
C                                 equals zero (0).
C
C              10) PERIOD1      - flags to indicate the time of the first and third
C                  PERIOD2        changes of rudder angle.  They are initially set
C                                 to zero (0).
C
C              11) WIDTH1       - distance ship has travelled in the global
C                                 y-direction, at the time of the first change of
C                                 rudder angle
C
C THE OUTPUT VARIABLE IS:
C
C               1) RESULTS      - array containing the required results obtained
C                                 from a particular manoeuvre.  The values in the
C                                 array RESULTS are listed above.
C
C DIMENSION VARIABLES
C
      DIMENSION RESULTS(5),YAWANG(4000),WIDTH(4000),Y(10)
C
C COMMON BLOCKS OF DATA
C
      COMMON /CONST/ RHO,GRAV,PI,KVIS
C
C DECLARE VARIABLES
C
      REAL KVIS
C
      IF (MNVRE .EQ. 1) THEN
C
C Turning circle manoeuvre
C
C Find the advance and transfer
C
            IF (ITIME .GT. 1) THEN
               IF (ABS(ABS(Y(6))-PI/2.) .LE. .008) THEN
                  RESULTS(1)=Y(2)-X1
                  RESULTS(2)=Y(4)-Y1
               ELSE IF ((ABS(YAWANG(ITIME)) .GT. (PI/2.)) .AND.
     &                  (ABS(YAWANG(ITIME-1)) .LT. (PI/2.))) THEN
                  RESULTS(1)=Y(2)-X1
                  RESULTS(2)=Y(4)-Y1
               END IF
C
C Find tactical diameter
C
               IF (ABS(ABS(Y(6))-PI) .LE. .008) THEN
                  RESULTS(3)=Y(4)-Y1
               ELSE IF ((ABS(YAWANG(ITIME)) .GT. PI) .AND.
     &                     (ABS(YAWANG(ITIME-1)) .LT. PI)) THEN
                    RESULTS(3)=Y(4)-Y1
                END IF
C
C Find steady turning diameter and steady turning speed
C
                IF (ABS(ABS(Y(6))-(2.*PI)) .LE. .008) THEN
                    RESULTS(4)=RESULTS(3)-Y(4)
                    RESULTS(5)=SQRT(Y(1)**2.+Y(3)**2.)
                  ELSE IF ((ABS(YAWANG(ITIME)) .GT. (2.*PI)) .AND.
     &                     (ABS(YAWANG(ITIME-1)) .LT. (2.*PI))) THEN
                    RESULTS(4)=RESULTS(3)-Y(4)
                    RESULTS(5)=SQRT(Y(1)**2.+Y(3)**2.)
                END IF
           END IF
         ELSE IF (MNVRE .EQ. 2) THEN
C
C Zigzag manoeuvre
C
C Find overshoot angle and overshoot width of path
C
           IF (ZIGZAG .LT. 2.) THEN
                WIDTH(ITIME)=Y(4)
                IF ((ITIME .GT. 1) .AND. (ANGMAX .GT. 0.)) THEN
                    AMAX=MAX(YAWANG(ITIME),YAWANG(ITIME-1))
                    IF ((AMAX-ANGMAX*PI/180.) .GT. RESULTS(1)) THEN
                         RESULTS(1)=AMAX-ANGMAX*PI/180.
                    END IF
                    WMAX=MAX(WIDTH(ITIME),WIDTH(ITIME-1))
                    IF (WMAX .GT. WIDTH1) THEN
                         IF ((WMAX-WIDTH1) .GT. RESULTS(2)) THEN
                              RESULTS(2)=WMAX-WIDTH1
                         END IF
                    END IF
                  ELSE IF((ITIME .GT. 1) .AND. (ANGMAX .LT. 0.)) THEN
                    AMAX=MIN(YAWANG(ITIME),YAWANG(ITIME-1))
                    IF ((ANGMAX*PI/180.-AMAX) .GT. RESULTS(1)) THEN
                         RESULTS(1)=ANGMAX*PI/180.-AMAX
                    END IF
                    WMAX=MIN(WIDTH(ITIME),WIDTH(ITIME-1))
                    IF (WMAX .LT. WIDTH1) THEN
                         IF ((WIDTH1-WMAX) .GT. RESULTS(2)) THEN
                              RESULTS(2)=WIDTH1-WMAX
                         END IF
                    END IF
                END IF
           END IF
C
C Find period which is defined as the time between the first change
C of rudder angle, and the third change of rudder angle.
C
           IF (PERIOD1 .EQ. 0.) THEN
                IF (ABS(ZIGZAG-1.) .LT. .001) THEN
                    PERIOD1=TIME
                END IF
           END IF
           IF (PERIOD2 .EQ. 0.) THEN
```

```
0172                    IF (ABS(ZIGZAG-3.) .LT. .001) THEN
0173                        PERIOD2=TIME
0174                        RESULTS(3)=PERIOD2-PERIOD1
0175                    END IF
0176                END IF
0177      C
0178      C Find reach which is defined as the distance travelled in the x-direction,
0179      C from the start of the manoeuvre to the time when the yaw angle first reaches
0180      C zero (0) degrees +- 0.5 deg.
0181      C
0182                IF ((ZIGZAG .LT. 2.) .AND. (ZIGZAG .GE. 1.)) THEN
0183                    IF (ABS(YAWANG(ITIME)) .LE. .008) THEN
0184                        RESULTS(4)=Y(2)-X1
0185                      ELSE IF ((YAWANG(ITIME) .GT. 0.) .AND.
0186           &                    (YAWANG(ITIME-1) .LT. 0.)) THEN
0187                        RESULTS(4)=Y(2)-X1
0188                      ELSE IF ((YAWANG(ITIME) .LT. 0.) .AND.
0189           &                    (YAWANG(ITIME-1) .GT. 0.)) THEN
0190                        RESULTS(4)=Y(2)-X1
0191                    END IF
0192                END IF
0193            END IF
0194      C
0195      C RETURN TO MAIN PROGRAM
0196      C
0197            RETURN
0198            END


PROGRAM SECTIONS

    Name                                 Bytes   Attributes

  0 $CODE                                  807   PIC CON REL LCL   SHR   EXE   RD NOWRT LONG
  2 $LOCAL                               16060   PIC CON REL LCL NOSHR NOEXE   RD   WRT LONG
  3 CONST                                   16   PIC OVR REL GBL   SHR NOEXE   RD   WRT LONG

    Total Space Allocated                16883

ENTRY POINTS

    Address   Type  Name

  0-00000000        TEST

VARIABLES

    Address   Type  Name                Address   Type  Name                Address   Type  Name                Address   Type  Name

      **      R*4   AMAX          AP-00000018@ R*4   ANGMAX          3-00000004  R*4   GRAV            AP-00000008@ I*4   ITIME
  3-0000000C  R*4   KVIS          AP-00000004@ I*4   MNVRE         AP-0000002C@ R*4   PERIOD1          AP-00000030@ R*4   PERIOD2
  3-00000008  R*4   PI             3-00000000  R*4   RHO           AP-0000000C@ R*4   TIME             AP-00000028@ R*4   WIDTH1
      **      R*4   WMAX          AP-00000020@ R*4   X1            AP-00000024@ R*4   Y1               AP-0000001C@ R*4   ZIGZAG
```

```
ARRAYS

    Address   Type  Name                  Bytes  Dimensions

  AP-00000034@ R*4  RESULTS                  20  (5)
   2-00000000  R*4  WIDTH                 16000  (4000)
  AP-00000010@ R*4  Y                        40  (10)
  AP-00000014@ R*4  YAWANG                16000  (4000)

FUNCTIONS AND SUBROUTINES REFERENCED

  Type  Name

   R*4  MTH$SQRT

COMMAND QUALIFIERS

  FOR/LIST MANOEUVRE

  /CHECK=(NOBOUNDS,OVERFLOW,NOUNDERFLOW)
  /DEBUG=(NOSYMBOLS,TRACEBACK)
  /STANDARD=(NOSYNTAX,NOSOURCE_FORM)
  /SHOW=(NOPREPROCESSOR,NOINCLUDE,MAP,NODICTIONARY,SINGLE)
  /WARNINGS=(GENERAL,NODECLARATIONS,NOULTRIX)
  /CONTINUATIONS=19  /NOCROSS_REFERENCE  /NOD_LINES  /NOEXTEND_SOURCE  /F77
  /NOG_FLOATING  /I4  /NOMACHINE_CODE  /OPTIMIZE  /NOANALYSIS

COMPILATION STATISTICS

  Run Time:             60.64 seconds
  Elapsed Time:         117.76 seconds
  Page Faults:          939
  Dynamic Memory:       645 pages
```

```
0000000000   99999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999
0000000000   99999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999
0000000000   9999999999999999999999999  Digital Equipment Corporation - VAX/VMS Version V4.6  9999999999999999999999999
             99999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999   0000000000
             99999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999   0000000000
                                                                                                                      0000000000

                                 L       AAA   N   N TTTTT  OOO   SSSS
                                 L      A   A  N   N   T   O   O S
                                 L      A   A  NN  N   T   O   O S
                                 L      A   A  N N N   T   O   O  SSS
                                 L      AAAAA  N  NN   T   O   O     S
                                 L      A   A  N   N   T   O   O     S
                                 LLLLL  A   A  N   N   T    OOO  SSSS

  AAA  L      GGGG   OOO  BBBB       1   55555  SSSS  PPPP   III  RRRR          DDDD   AAA  TTTTT        1
 A   A L     G      O   O B   B     11   5     S      P   P   I   R   R         D   D A   A   T    ''   11
 A   A L     G      O   O B   B      1   555   S      P   P   I   R   R         D   D A   A   T    ''    1
 AAAAA L     G  GGG O   O BBBB       1      5   SSS   PPPP    I   RRRR          D   D AAAAA   T          1
 A   A L     G   G  O   O B   B      1      5      S  P       I   R R           D   D A   A   T    ''    1
 A   A L     G   G  O   O B   B      1   5  5      S  P       I   R  R     ..   D   D A   A   T    ''    1
 A   A LLLLL  GGG    OOO  BBBB      111   555  SSSS   P      III  R   R    ..   DDDD  A   A   T    '    111






File  DUA1:[LANTOS]ALGOB-15SPIR.DAT;1 (1163,60,0), last revised on 29-JUL-1988 13:38, is a 1 block sequential file owned by UIC
[QANDM,LANTOS].  The records are variable length with implied (CR) carriage control.  The longest record is 62 bytes.

Job ALGOB-15SPIR (221) queued to SYS$PRINT on 28-SEP-1988 10:14 by user LANTOS, UIC [QANDM,LANTOS], under account QANDM at priority
100, started on printer _TXA3: on 28-SEP-1988 10:24 from queue SYS$PRINT.

0000000000   99999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999
0000000000   99999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999
0000000000   9999999999999999999999999  Digital Equipment Corporation - VAX/VMS Version V4.6  9999999999999999999999999
             99999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999   0000000000
             99999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999   0000000000
                                                                                                                      0000000000
```

```
1000.,1.14E-6,1.14,18,3.268E5
218.8,218.8,23.12,6.71,3.35,0.88,0.996,0.914,2.19E7
0.,0.,0.,0.,6.43,0.,0.,0.,2.,0.,0.,0.,0.,0.,0.45,0.
-110.,6.28,0.45,25.1,3.35,1.57,2.52,3.,0.,11,150.,0.,0,1,0.005
2.134,3.15,1.68,1
50.2,1.4
3,4000.,1.,-15.,10,5.7,0.96,0.5,4,5.4E6,2
-108.4,7.93,6.43,1,1,3.15,1.,3,5.
```

```
VVVVVVVVV     00000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000     VVVVVVVVV
VVVVVVVVV     0000000000000000000000000  Digital Equipment Corporation - VAX/VMS Version V4.6  0000000000000000000000000     VVVVVVVVV
VVVVVVVVV     00000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000     VVVVVVVVV

                                                L       AAA   N   N  TTTTT   OOO    SSSS
                                                L      A   A  N   N    T    O   O  S
                                                L      A   A  NN  N    T    O   O  S
                                                L      A   A  N N N    T    O   O   SSS
                                                L      AAAAA  N  NN    T    O   O      S
                                                L      A   A  N   N    T    O   O      S
                                                LLLLL  A   A  N   N    T     OOO   SSSS

                                       SSSSSSSS      IIIIII    MM      MM  UU      UU  LL
                                       SSSSSSSS      IIIIII    MM      MM  UU      UU  LL
                                     SS                II      MMMM  MMMM  UU      UU  LL
                                     SS                II      MMMM  MMMM  UU      UU  LL
                                     SS                II      MM  MM  MM  UU      UU  LL
                                     SS                II      MM  MM  MM  UU      UU  LL
                                       SSSSSS          II      MM      MM  UU      UU  LL
                                       SSSSSS          II      MM      MM  UU      UU  LL
                                             SS        II      MM      MM  UU      UU  LL
                                             SS        II      MM      MM  UU      UU  LL
                                             SS        II      MM      MM  UU      UU  LL
                                             SS        II      MM      MM  UU      UU  LL
                                     SSSSSSSS        IIIIII    MM      MM  UUUUUUUUUU  LLLLLLLLLL
                                     SSSSSSSS        IIIIII    MM      MM  UUUUUUUUUU  LLLLLLLLLL

                                              OOOOOO     UU      UU  TTTTTTTTTT       ;;;;        11
                                              OOOOOO     UU      UU  TTTTTTTTTT       ;;;;        11
                                            OO      OO   UU      UU      TT           ;;;;      1111
                                            OO      OO   UU      UU      TT           ;;;;      1111
                                            OO      OO   UU      UU      TT                       11
                                            OO      OO   UU      UU      TT                       11
                                            OO      OO   UU      UU      TT           ;;;;        11
                                            OO      OO   UU      UU      TT           ;;;;        11
                                            OO      OO   UU      UU      TT           ;;;;        11
                                            OO      OO   UU      UU      TT           ;;;;        11
                                    ....    OO      OO   UU      UU      TT             ;;        11
                                    ....    OO      OO   UU      UU      TT             ;;        11
                                    ....      OOOOOO     UUUUUUUUUU      TT           ;;          111111
                                    ....      OOOOOO     UUUUUUUUUU      TT           ;;          111111

File _DUA1:[LANTOS]SIMUL.OUT;1 (1408,79,0), last revised on 28-SEP-1988 10:37, is a 58 block sequential file owned by UIC
[GANDM,LANTOS].  The records are variable length with FORTRAN (FTN) carriage control.  The longest record is 116 bytes.

Job SIMUL (226) queued to SYS$PRINT on 28-SEP-1988 10:52 by user LANTOS, UIC [GANDM,LANTOS], under account GANDM at priority 100,
started on printer _TXA3: on 28-SEP-1988 11:06 from queue SYS$PRINT.

VVVVVVVVV     00000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000     VVVVVVVVV
VVVVVVVVV     0000000000000000000000000  Digital Equipment Corporation - VAX/VMS Version V4.6  0000000000000000000000000     VVVVVVVVV
VVVVVVVVV     00000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000     VVVVVVVVV
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                                   INPUT DATA
                                SPIRAL MANOEUVRE
*******************************************************************************
                   DESCRIPTION                         VALUE            UNITS
-------------------------------------------------------------------------------
LENGTH BETWEEN PERPENDICULARS                          218.80           METERS
LENGTH ON WATERLINE                                    218.80           METERS
BREADTH                                                 23.12           METERS
DRAFT AFT                                                6.71           METERS
DRAFT FWD                                                3.35           METERS
DISPLACEMENT                                         21900.00           TONNES
BLOCK COEFFICIENT                                        0.88           -----
MIDSHIP SECTION COEFFICIENT                              1.00           -----
WATERPLANE COEFFICIENT                                   0.91           -----
RUDDER LATERAL AREA                                     25.1         SQ. METERS
PROPELLER DIAMETER                                       5.70           METERS
PROPELLER PITCH/DIAMETER RATIO                           0.96           -----
PROPELLER EXPANDED BLADE AREA RATIO                      0.50           -----
SHAFT HORSEPOWER                                       5400.0             KW
*******************************************************************************
                           SHIP SPEED - POWER DATA
 SPEED     WAVE       APPEND     BULB BOW    TRANSOM      CORR.      FRICTION     TOTAL      EFFECTIVE
          RESIST      RESIST      RESIST      RESIST     RESIST       RESIST      RESIST     HORSEPOWER
(KNOTS)    (KN)        (KN)        (KN)        (KN)       (KN)         (KN)        (KN)         (KW)
*******************************************************************************************************
 10.0   0.149E+02   0.332E+01   0.597E+00   0.000E+00   0.448E+02   0.129E+03   0.229E+03   0.118E+04
 11.0   0.309E+02   0.400E+01   0.673E+00   0.000E+00   0.542E+02   0.155E+03   0.288E+03   0.163E+04
 12.0   0.569E+02   0.473E+01   0.744E+00   0.000E+00   0.645E+02   0.182E+03   0.360E+03   0.222E+04
 13.0   0.960E+02   0.553E+01   0.811E+00   0.000E+00   0.757E+02   0.212E+03   0.449E+03   0.300E+04
 14.0   0.151E+03   0.639E+01   0.872E+00   0.000E+00   0.877E+02   0.243E+03   0.557E+03   0.402E+04
 15.0   0.224E+03   0.731E+01   0.928E+00   0.000E+00   0.101E+03   0.277E+03   0.687E+03   [illegible]
 16[illegible] [illegible] [illegible] [illegible] 0.000E+00   0.115E+03   0.313E+03   0.841E+03   0.692E+04
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   17.0    0.431E+03   0.933E+01   0.103E+01   0.000E+00   0.129E+03   0.350E+03   0.102E+04    0.891E+04
   18.0    0.567E+03   0.104E+02   0.107E+01   0.000E+00   0.145E+03   0.390E+03   0.122E+04    0.113E+05
   19.0    0.728E+03   0.116E+02   0.111E+01   0.000E+00   0.162E+03   0.432E+03   0.146E+04    0.142E+05
   20.0    0.908E+03   0.128E+02   0.115E+01   0.000E+00   0.179E+03   0.476E+03   0.171E+04    0.176E+05
  WAKE FRACTION =  0.450
  THRUST DEDUCTION FRACTION =  0.160
  FORM FACTOR OF THE HULL =  0.281
  The friction resistance in the above table was
  multiplied by (1.+CFORM) to obtain the total
  resistance.
  ******************************************************************************************************
    TIME       LOCAL        LOCAL          LOCAL           GLOBAL          GLOBAL      YAW ANGLE   ROLL ANGLE   PROPELLER
              X-SPEED      Y-SPEED       SHIP SPEED      X-POSITION      Y-POSITION                               SPEED
   (SECS)     (KNOTS)      (KNOTS)        (KNOTS)         (METERS)        (METERS)    (DEGREES)    (DEGREES)     (RPM)
  ******************************************************************************************************
      0.0      12.50         0.00          12.50              0.00            0.00         0.0          0.0        120.0
     10.0      12.94         0.46          12.95             65.50            0.51        -1.4          0.0        120.5
     20.0      13.31         1.02          13.35            133.18            0.64        -5.2          0.0        120.9
     30.0      13.60         1.46          13.68            202.67           -2.10       -10.1          0.1        121.2
     40.0      13.83         1.74          13.94            273.31           -9.61       -15.5          0.1        121.4
     50.0      14.01         1.92          14.14            344.28          -23.04       -21.0          0.2        121.6
     60.0      14.17         2.03          14.32            414.69          -43.02       -26.6          0.2        121.8
     70.0      14.31         2.09          14.46            483.69          -69.81       -32.3          0.2        122.0
     80.0      14.44         2.12          14.59            550.41         -103.44       -37.9          0.2        122.1
     90.0      14.55         2.15          14.71            614.05         -143.76       -43.6          0.2        122.2
    100.0      14.65         2.16          14.81            673.85         -190.51       -49.3          0.2        122.4
    110.0      14.75         2.17          14.91            729.10         -243.31       -54.9          0.2        122.5
    120.0      14.84         2.18          15.00            779.13         -301.70       -60.6          0.2        122.6
    130.0      14.92         2.19          15.08            823.34         -365.14       -66.3          0.2        122.7
    140.0      14.99         2.19          15.15            861.19         -433.01       -72.0          0.2        122.8
  RUDDER ANGLE =  -10.00000
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     150.0      15.06       2.20      15.22         892.22      -504.67      -77.8         0.2        122.8
     160.0      15.20       2.06      15.34         915.92      -579.55      -83.0         0.2        123.0
     170.0      15.36       1.95      15.48         932.54      -657.03      -87.7         0.2        123.2
     180.0      15.52       1.88      15.64         942.43      -736.43      -92.2         0.2        123.4
     190.0      15.68       1.84      15.79         945.68      -817.17      -96.7         0.2        123.5
     200.0      15.83       1.82      15.93         942.35      -898.67     -101.2         0.2        123.7
     210.0      15.97       1.81      16.07         932.40      -980.37     -105.7         0.2        123.9
     220.0      16.10       1.81      16.20         915.86     -1061.70     -110.2         0.2        124.0
     230.0      16.22       1.80      16.32         892.75     -1142.08     -114.7         0.2        124.2
     240.0      16.34       1.81      16.43         863.16     -1220.95     -119.1         0.2        124.3
     250.0      16.44       1.81      16.54         827.18     -1297.74     -123.6         0.2        124.4
     260.0      16.54       1.81      16.64         785.00     -1371.89     -128.1         0.2        124.6
     270.0      16.63       1.81      16.73         736.83     -1442.88     -132.7         0.2        124.7
 RUDDER ANGLE =   -5.000000

     280.0      16.72       1.78      16.81         682.90     -1510.17     -137.1         0.2        124.8
     290.0      16.86       1.61      16.94         623.37     -1573.30     -140.9         0.2        125.0
     300.0      17.02       1.46      17.08         559.01     -1632.55     -144.1         0.1        125.2
     310.0      17.18       1.36      17.23         490.51     -1688.19     -147.1         0.1        125.3
     320.0      17.33       1.30      17.38         418.34     -1740.30     -150.0         0.1        125.5
     330.0      17.48       1.26      17.52         342.83     -1788.86     -152.9         0.1        125.7
     340.0      17.62       1.23      17.66         264.27     -1833.79     -155.7         0.1        125.9
     350.0      17.75       1.22      17.79         182.92     -1874.98     -158.5         0.1        126.0
     360.0      17.87       1.21      17.91          99.03     -1912.31     -161.3         0.1        126.2
     370.0      17.98       1.20      18.02          12.83     -1945.64     -164.1         0.1        126.3
     380.0      18.09       1.20      18.13         -75.44     -1974.83     -166.9         0.1        126.5
     390.0      18.18       1.20      18.22        -165.53     -1999.78     -169.7         0.1        126.6
     400.0      18.27       1.20      18.31        -257.21     -2020.37     -172.5         0.1        126.7
     410.0      18.35       1.20      18.39        -350.22     -2036.50     -175.3         0.1        126.8
 RUDDER ANGLE =   0.0000000E+00
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    420.0     18.45      1.02      18.48       -444.34    -2047.96    -177.7       0.1      126.9
    430.0     18.57      0.79      18.59       -539.39    -2055.26    -179.1       0.1      127.1
    440.0     18.69      0.60      18.70       -635.19    -2059.57    -180.0       0.1      127.2
    450.0     18.81      0.45      18.81       -731.65    -2061.69    -180.6       0.1      127.4
    460.0     18.92      0.33      18.92       -828.70    -2062.20    -181.1       0.0      127.5
    470.0     19.02      0.25      19.02       -926.30    -2061.52    -181.4       0.0      127.6
    480.0     19.12      0.19      19.12      -1024.39    -2059.94    -181.7       0.0      127.8
    490.0     19.21      0.14      19.21      -1122.95    -2057.69    -181.9       0.0      127.9
    500.0     19.29      0.10      19.29      -1221.93    -2054.93    -182.0       0.0      128.0
    510.0     19.36      0.08      19.36      -1321.31    -2051.80    -182.1       0.0      128.1
    520.0     19.43      0.06      19.43      -1421.05    -2048.37    -182.2       0.0      128.2
    530.0     19.50      0.04      19.50      -1521.13    -2044.72    -182.3       0.0      128.2
    540.0     19.56      0.03      19.56      -1621.52    -2040.90    -182.3       0.0      128.3
    550.0     19.61      0.02      19.61      -1722.19    -2036.95    -182.3       0.0      128.4
    560.0     19.66      0.02      19.66      -1823.13    -2032.91    -182.4       0.0      128.5
 RUDDER ANGLE =    5.000000

    570.0     19.71     -0.01      19.71      -1924.32    -2028.78    -182.4       0.0      128.5
    580.0     19.73     -0.32      19.73      -2025.67    -2024.41    -181.4       0.0      128.6
    590.0     19.74     -0.64      19.75      -2127.17    -2021.02    -179.5      -0.1      128.6
    600.0     19.73     -0.87      19.75      -2228.76    -2020.14    -177.0      -0.1      128.6
    610.0     19.71     -1.03      19.74      -2330.29    -2022.82    -174.3      -0.1      128.5
    620.0     19.68     -1.13      19.71      -2431.51    -2029.74    -171.5      -0.1      128.5
    630.0     19.65     -1.19      19.69      -2532.18    -2041.30    -168.6      -0.1      128.5
    640.0     19.62     -1.23      19.66      -2632.02    -2057.71    -165.7      -0.1      128.4
    650.0     19.59     -1.25      19.63      -2730.77    -2079.06    -162.7      -0.1      128.4
    660.0     19.56     -1.26      19.60      -2828.15    -2105.37    -159.7      -0.1      128.3
    670.0     19.53     -1.27      19.57      -2923.91    -2136.62    -156.7      -0.1      128.3
    680.0     19.50     -1.28      19.54      -3017.79    -2172.73    -153.7      -0.1      128.3
    690.0     19.48     -1.28      19.52      -3109.55    -2213.62    -150.7      -0.1      128.2
    700.0     19.45     -1.28      19.50      -3198.95    -2259.18    -147.7      -0.1      128.2
    710. 0     19. 43     -1. 28      19. 47     -3285. 76    -2309. 28     -144. 7      -0. 1      128. 2
 RUDDER ANGLE =    10. 00000

    720. 0     19. 39     -1. 37      19. 44     -3369. 77    -2363. 73     -141. 6      -0. 1      128. 1
    730. 0     19. 29     -1. 61      19. 36     -3450. 54    -2422. 34     -137. 5      -0. 2      128. 0
    740. 0     19. 17     -1. 77      19. 25     -3526. 88    -2485. 85     -132. 9      -0. 2      127. 9
    750. 0     19. 04     -1. 87      19. 14     -3597. 84    -2554. 49     -128. 1      -0. 2      127. 7
    760. 0     18. 92     -1. 93      19. 02     -3662. 69    -2628. 11     -123. 2      -0. 2      127. 5
    770. 0     18. 80     -1. 95      18. 90     -3720. 91    -2706. 33     -118. 3      -0. 2      127. 4
    780. 0     18. 69     -1. 96      18. 79     -3772. 10    -2788. 64     -113. 5      -0. 2      127. 2
    790. 0     18. 59     -1. 97      18. 69     -3815. 93    -2874. 48     -108. 6      -0. 2      127. 1
    800. 0     18. 49     -1. 97      18. 60     -3852. 18    -2963. 25     -103. 7      -0. 2      127. 0
    810. 0     18. 41     -1. 97      18. 51     -3880. 67    -3054. 31      -98. 8      -0. 2      126. 9
    820. 0     18. 33     -1. 97      18. 43     -3901. 26    -3147. 05      -94. 0      -0. 2      126. 8
    830. 0     18. 25     -1. 96      18. 36     -3913. 89    -3240. 80      -89. 1      -0. 2      126. 7
    840. 0     18. 19     -1. 96      18. 29     -3918. 55    -3334. 92      -84. 2      -0. 2      126. 6
 RUDDER ANGLE =    15. 00000

    850. 0     18. 11     -2. 00      18. 22     -3915. 27    -3428. 77      -79. 4      -0. 2      126. 5
    860. 0     17. 95     -2. 18      18. 08     -3904. 26    -3521. 47      -73. 7      -0. 2      126. 3
    870. 0     17. 77     -2. 30      17. 92     -3884. 78    -3611. 96      -67. 6      -0. 2      126. 1
    880. 0     17. 59     -2. 36      17. 75     -3856. 52    -3699. 19      -61. 4      -0. 3      125. 9
    890. 0     17. 42     -2. 39      17. 58     -3819. 64    -3782. 19      -55. 2      -0. 3      125. 7
    900. 0     17. 26     -2. 40      17. 43     -3774. 56    -3860. 09      -48. 9      -0. 3      125. 5
    910. 0     17. 11     -2. 41      17. 28     -3721. 88    -3932. 10      -42. 7      -0. 3      125. 3
    920. 0     16. 98     -2. 40      17. 15     -3662. 27    -3997. 52      -36. 5      -0. 3      125. 1
    930. 0     16. 85     -2. 40      17. 02     -3596. 49    -4055. 73      -30. 3      -0. 2      125. 0
    940. 0     16. 74     -2. 39      16. 91     -3525. 35    -4106. 21      -24. 1      -0. 2      124. 8
    950. 0     16. 63     -2. 39      16. 80     -3449. 70    -4148. 52      -18. 0      -0. 2      124. 7
    960. 0     16. 54     -2. 38      16. 71     -3370. 43    -4182. 29      -11. 8      -0. 2      124. [illegible]
    [illegible]0     [illegible]. 45     -2. [illegible]      [illegible]6. 6[illegible]     -[illegible]288. [illegible]    -[illegible]207. 28      [illegible]. 7      -0. 2      124. [illegible]
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RUDDER ANGLE =   10.00000

   980.0     16.41      -2.29      16.57      -3204.67     -4223.22      0.3     -0.3     124.4
   990.0     16.45      -2.14      16.59      -3119.73     -4230.18      5.5     -0.2     124.5
  1000.0     16.50      -2.04      16.63      -3034.34     -4228.99     10.4     -0.2     124.5
  1010.0     16.56      -1.98      16.68      -2949.15     -4220.13     15.3     -0.2     124.6
  1020.0     16.63      -1.95      16.74      -2864.76     -4203.85     20.0     -0.2     124.7
  1030.0     16.69      -1.93      16.80      -2781.78     -4180.37     24.8     -0.2     124.8
  1040.0     16.75      -1.92      16.85      -2700.79     -4149.87     29.6     -0.2     124.8
  1050.0     16.80      -1.92      16.91      -2622.39     -4112.57     34.4     -0.2     124.9
  1060.0     16.85      -1.91      16.96      -2547.16     -4068.70     39.1     -0.2     124.9
  1070.0     16.89      -1.91      17.00      -2475.66     -4018.57     43.9     -0.2     125.0
  1080.0     16.94      -1.91      17.05      -2408.42     -3962.49     48.7     -0.2     125.1
  1090.0     16.98      -1.92      17.08      -2345.95     -3900.84     53.5     -0.2     125.1
  1100.0     17.01      -1.92      17.12      -2288.72     -3834.05     58.2     -0.2     125.1
RUDDER ANGLE =   5.000000

  1110.0     17.08      -1.80      17.18      -2237.23     -3762.48     62.8     -0.2     125.2
  1120.0     17.20      -1.62      17.27      -2191.54     -3686.60     66.4     -0.2     125.4
  1130.0     17.33      -1.49      17.39      -2150.99     -3607.20     69.7     -0.2     125.5
  1140.0     17.46      -1.40      17.52      -2115.21     -3524.86     72.8     -0.1     125.7
  1150.0     17.59      -1.34      17.64      -2084.07     -3439.97     75.8     -0.1     125.8
  1160.0     17.71      -1.31      17.76      -2057.53     -3352.89     78.8     -0.1     126.0
  1170.0     17.82      -1.29      17.87      -2035.60     -3263.92     81.8     -0.1     126.1
  1180.0     17.93      -1.28      17.98      -2018.33     -3173.35     84.8     -0.1     126.3
  1190.0     18.03      -1.27      18.07      -2005.80     -3081.48     87.8     -0.1     126.4
  1200.0     18.12      -1.27      18.17      -1998.06     -2988.59     90.7     -0.1     126.5
  1210.0     18.21      -1.27      18.25      -1995.16     -2894.97     93.7     -0.1     126.6
  1220.0     18.29      -1.26      18.33      -1997.17     -2800.91     96.7     -0.1     126.7
  1230.0     18.36      -1.26      18.40      -2004.09     -2706.69     99.6     -0.1     126.8
RUDDER ANGLE =   0.0000000E+00
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   1240.0     18.43     -1.22     18.47     -2015.97     -2612.60     102.6     -0.2     126.9
   1250.0     18.53     -0.98     18.56     -2032.92     -2518.90     104.6     -0.1     127.0
   1260.0     18.65     -0.74     18.66     -2053.80     -2425.48     105.8     -0.1     127.2
   1270.0     18.76     -0.56     18.77     -2077.53     -2332.16     106.6     -0.1     127.3
   1280.0     18.88     -0.41     18.88     -2103.37     -2238.81     107.2      0.0     127.5
   1290.0     18.98     -0.31     18.98     -2130.80     -2145.36     107.6      0.0     127.6
   1300.0     19.08     -0.23     19.08     -2159.44     -2051.72     108.0      0.0     127.7
   1310.0     19.17     -0.17     19.17     -2189.01     -1957.86     108.2      0.0     127.8
   1320.0     19.26     -0.13     19.26     -2219.30     -1863.76     108.4      0.0     127.9
   1330.0     19.34     -0.10     19.34     -2250.15     -1769.40     108.5      0.0     128.0
   1340.0     19.41     -0.07     19.41     -2281.45     -1674.78     108.6      0.0     128.1
   1350.0     19.47     -0.05     19.47     -2313.11     -1579.91     108.7      0.0     128.2
   1360.0     19.54     -0.04     19.54     -2345.05     -1484.79     108.7      0.0     128.3
   1370.0     19.59     -0.03     19.59     -2377.23     -1389.43     108.8      0.0     128.4
   1380.0     19.64     -0.02     19.64     -2409.60     -1293.84     108.8      0.0     128.4
   1390.0     19.69     -0.02     19.69     -2442.13     -1198.04     108.8      0.0     128.5
 RUDDER ANGLE =  -5.000000

   1400.0     19.73      0.08     19.73     -2474.84     -1102.05     108.7     -0.1     128.6
   1410.0     19.75      0.39     19.75     -2507.66     -1005.94     107.5      0.0     128.6
   1420.0     19.75      0.67     19.77     -2539.20      -909.31     105.5      0.1     128.6
   1430.0     19.75      0.87     19.77     -2568.20      -811.85     103.1      0.1     128.6
   1440.0     19.73      1.00     19.75     -2593.79      -713.47     100.6      0.1     128.6
   1450.0     19.70      1.09     19.73     -2615.35      -614.23      97.9      0.1     128.5
   1460.0     19.68      1.14     19.71     -2632.50      -514.24      95.1      0.1     128.5
   1470.0     19.65      1.17     19.69     -2645.01      -413.69      92.3      0.1     128.5
   1480.0     19.62      1.19     19.66     -2652.72      -312.79      89.5      0.1     128.4
   1490.0     19.60      1.20     19.64     -2655.55      -211.76      86.7      0.1     128.4
   1500.0     19.57      1.21     19.61     -2653.45      -110.84   [illegible]  0.1     128.4
 [illegible]  19.55      1.21     19.59     -2646.42       -10.27      81.0      0.1     128.3
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  1520.0    19.53     1.22     19.57     -2634.47      89.73     78.2     0.1     128.3
  1530.0    19.51     1.22     19.55     -2617.62     188.93     75.4     0.1     128.3
  1540.0    19.49     1.22     19.53     -2595.92     287.07     72.5     0.1     128.3
RUDDER ANGLE =  -10.00000
  1550.0    19.44     1.37     19.49     -2569.54     383.93     69.4     0.2     128.2
  1560.0    19.34     1.58     19.41     -2538.18     478.92     65.3     0.2     128.1
  1570.0    19.23     1.72     19.31     -2500.85     571.22     60.8     0.2     127.9
  1580.0    19.11     1.80     19.20     -2457.15     660.08     56.3     0.2     127.8
  1590.0    19.00     1.85     19.09     -2407.07     744.86     51.6     0.2     127.6
  1600.0    18.89     1.87     18.99     -2350.81     824.99     47.0     0.2     127.5
  1610.0    18.79     1.88     18.89     -2288.67     899.99     42.3     0.2     127.4
  1620.0    18.70     1.89     18.80     -2221.07     969.42     37.7     0.2     127.3
  1630.0    18.62     1.89     18.71     -2148.44    1032.89     33.1     0.2     127.1
  1640.0    18.54     1.89     18.63     -2071.28    1090.07     28.4     0.2     127.1
  1650.0    18.47     1.89     18.56     -1990.09    1140.64     23.8     0.2     127.0
  1660.0    18.40     1.88     18.50     -1905.41    1184.35     19.1     0.2     126.9
  1670.0    18.34     1.88     18.44     -1817.78    1220.99     14.5     0.2     126.8
RUDDER ANGLE =  -15.00000
  1680.0    18.26     1.95     18.36     -1727.81    1250.41      9.8     0.2     126.7
  1690.0    18.10     2.12     18.23     -1636.31    1272.35      4.3     0.2     126.5
  1700.0    17.94     2.22     18.07     -1543.94    1285.77     -1.6     0.2     126.3
  1710.0    17.77     2.28     17.92     -1451.50    1290.11.    -7.5     0.2     126.1
  1720.0    17.62     2.31     17.77     -1359.89    1285.19    -13.4     0.2     125.9
  1730.0    17.47     2.32     17.62     -1269.99    1271.11    -19.4     0.2     125.7
  1740.0    17.34     2.32     17.49     -1182.70    1248.10    -25.3     0.2     125.6
  1750.0    17.21     2.31     17.37     -1098.84    1216.50    -31.3     0.2     125.4
  1760.0    17.10     2.31     17.26     -1019.19    1176.74    -37.2     0.2     125.3
  1770.0    17.00     2.31     17.15      -944.51    1129.33    -43.1     0.2     125.1
  1780.0    16.90     2.30     17.06      -875.48    1074.84    -49.0     0.2     125.0
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   1790.0     16.81      2.30      16.97       -812.70     1013.90      -54.9       0.2       124.9
   1800.0     16.73      2.29      16.89       -756.76      947.20      -60.7       0.2       124.8
RUDDER ANGLE =  -20.00000

END OF SPIRAL TEST

                              RESULTS FROM TIME SIMULATION ANALYSIS
                                         SPIRAL MANOEUVRE
 *******************************************************************************************************
                     DESCRIPTION                                         VALUE                    UNITS
 -------------------------------------------------------------------------------------------------------
 THE RESULTS FOR THE SPIRAL TEST ARE SUMMARIZED BELOW.  THEY ARE THE
 CONSTANT RATES OF TURN AT EACH RUDDER ANGLE, STARTING WITH THE INITIAL
 ANGLE, AND SUBSEQUENTLY CHANGING BY "DELTANG".
 THE INITIAL RUDDER ANGLE IS                                             -15.00                   DEGREES
 THE CHANGE OF RUDDER ANGLE IS                                             5.00                   DEGREES
  THE ANGLE IS = -15.0
THE CONSTANT YAW RATE IS                                                 -0.572E+00               DEG./SEC.
  THE ANGLE IS = -10.0
THE CONSTANT YAW RATE IS                                                 -0.452E+00               DEG./SEC.
  THE ANGLE IS =  -5.0
THE CONSTANT YAW RATE IS                                                 -0.280E+00               DEG./SEC.
  THE ANGLE IS =   0.0
THE CONSTANT YAW RATE IS                                                 -0.171E-02               DEG./SEC.
  THE ANGLE IS =   5.0
THE CONSTANT YAW RATE IS                                                  0.299E+00               DEG./SEC.
  THE ANGLE IS =  10.0
THE CONSTANT YAW RATE IS                                                  0.485E+00               DEG./SEC.
  THE ANGLE IS =  15.0
THE CONSTANT YAW RATE IS                                                  0.615E+00               DEG./SEC.
  THE ANGLE IS =  10.0
THE CONSTANT YAW RATE IS                                                  0.478E+00               DEG./SEC.
  THE ANGLE IS =   5.0
THE CONSTANT YAW RATE IS                                                  0.297E+00               DEG./SEC.
  THE ANGLE [illegible]
THE [illegible]ANT [illegible] RA[illegible]IS                                                  0.172E-02               DEG./SEC.
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  THE ANGLE IS =  -5.0
THE CONSTANT YAW RATE IS                                  -0.283E+00                 DEG./SEC.

  THE ANGLE IS = -10.0
THE CONSTANT YAW RATE IS                                  -0.462E+00                 DEG./SEC.

  THE ANGLE IS = -15.0
THE CONSTANT YAW RATE IS                                  -0.588E+00                 DEG./SEC.
 ****************************************************************************************************

                                  RESULTS FROM THE EMPIRICAL ANALYSIS

                                        CRASH STOP MANOEUVRE
 ****************************************************************************************************
                  DESCRIPTION                                       VALUE                  UNITS
 ----------------------------------------------------------------------------------------------------
 INITIAL SPEED OF SHIP                                               12.50                 KNOTS
 INITIAL RESISTANCE OF SHIP                                         404.6                   KN
 MAXIMUM ASTERN THRUST                                              326.8                   KN
 NON-DIMENSIONAL HEAD REACH (REACH/LPP)                               4.36                 -----
 ****************************************************************************************************
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RRRRRRRRRR    99999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999
RRRRRRRRRR    9999999999999999999999999  Digital Equipment Corporation - VAX/VMS Version V4.6  9999999999999999999999999    RRRRRRRRRR
RRRRRRRRRR    99999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999    RRRRRRRRRR
                                                                                                                         RRRRRRRRRR

                                 L       AAA   N   N  TTTTT   OOO   SSSS
                                 L      A   A  N   N    T    O   O S
                                 L      A   A  NN  N    T    O   O S
                                 L      A   A  N N N    T    O   O  SSS
                                 L      AAAAA  N  NN    T    O   O     S
                                 L      A   A  N   N    T    O   O     S
                                 LLLLL  A   A  N   N    T     OOO  SSSS

  AAAAAA    LL            GGGGGGGG    OOOOOO    BBBBBBBB          333333    5555555555    CCCCCCCC  IIIIII  RRRRRRRR
  AAAAAA    LL            GGGGGGGG    OOOOOO    BBBBBBBB          333333    5555555555    CCCCCCCC  IIIIII  RRRRRRRR
AA      AA  LL          GG          OO      OO  BB      BB      33      33  55          CC            II    RR      RR
AA      AA  LL          GG          OO      OO  BB      BB      33      33  55          CC            II    RR      RR
AA      AA  LL          GG          OO      OO  BB      BB              33  555555      CC            II    RR      RR
AA      AA  LL          GG          OO      OO  BB      BB              33  555555      CC            II    RR      RR
AA      AA  LL          GG          OO      OO  BBBBBBBB              33          55    CC            II    RRRRRRRR
AA      AA  LL          GG          OO      OO  BBBBBBBB              33          55    CC            II    RRRRRRRR
AAAAAAAAAA  LL          GG  GGGGGG  OO      OO  BB      BB              33          55  CC            II    RR  RR
AAAAAAAAAA  LL          GG  GGGGGG  OO      OO  BB      BB              33          55  CC            II    RR  RR
AA      AA  LL          GG      GG  OO      OO  BB      BB      33      33  55      55  CC            II    RR    RR
AA      AA  LL          GG      GG  OO      OO  BB      BB      33      33  55      55  CC            II    RR    RR
AA      AA  LLLLLLLLLL    GGGGGG      OOOOOO    BBBBBBBB          333333      555555      CCCCCCCC  IIIIII  RR      RR
AA      AA  LLLLLLLLLL    GGGGGG      OOOOOO    BBBBBBBB          333333      555555      CCCCCCCC  IIIIII  RR      RR

                              DDDDDDDD      AAAAAA    TTTTTTTTTT    ;;;;      11
                              DDDDDDDD      AAAAAA    TTTTTTTTTT    ;;;;      11
                              DD      DD  AA      AA      TT        ;;;;    1111
                              DD      DD  AA      AA      TT        ;;;;    1111
                              DD      DD  AA      AA      TT                  11
                              DD      DD  AA      AA      TT                  11
                              DD      DD  AA      AA      TT        ;;;;      11
                              DD      DD  AA      AA      TT        ;;;;      11
                              DD      DD  AAAAAAAAAA      TT        ;;;;      11
                              DD      DD  AAAAAAAAAA      TT        ;;;;      11
                              DD      DD  AA      AA      TT         ;;       11
                              DD      DD  AA      AA      TT         ;;       11
                              DDDDDDDD    AA      AA      TT       ;;     111111
                              DDDDDDDD    AA      AA      TT       ;;     111111

File  DUA1:[LANTOS]ALGOB-35CIR.DAT;1 (153,171,0), last revised on 29-JUL-1988 13:36, is a 1 block sequential file owned by UIC
[GANDM,LANTOS].  The records are variable length with implied (CR) carriage control.  The longest record is 62 bytes.

Job ALGOB-15SPIR (221) queued to SYS$PRINT on 28-SEP-1988 10:14 by user LANTOS, UIC [GANDM,LANTOS], under account GANDM at priority
100, started on printer _TXA3: on 28-SEP-1988 10:24 from queue SYS$PRINT.

RRRRRRRRRR    99999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999
RRRRRRRRRR    9999999999999999999999999  Digital Equipment Corporation - VAX/VMS Version V4.6  9999999999999999999999999    RRRRRRRRRR
RRRRRRRRRR    99999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999    RRRRRRRRRR
                                                                                                                         RRRRRRRRRR
```

```
1000.,1.14E-6,1,14.18,3.268E5
218.8,218.8,23.12,6.71,3.35,0.88,0.996,0.914,2.19E7
0.,0.,0.,0.,6.43,0.,0.,0.,2.,0.,0.,0.,0.,0.,0.45,0.
-110.,6.28,0.45,25.1,3.35,1.57,2.52,3.,0.,11,150.,0.,0,1,0.005
2.134,3.15,1.68,1
50.2,1.4
1,4000.,1.,-35.,10,5.7,0.96,0.5,4,5.4E6,2
-108.4,7.93,6.43,1,1,3.15,1.,3,5.
```

```
UUUUUUUUUU     0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000     UUUUUUUUUU
UUUUUUUUUU     0000000000000000000000000  Digital Equipment Corporation - VAX/VMS Version V4.6  0000000000000000000000000     UUUUUUUUUU
UUUUUUUUUU     0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000     UUUUUUUUUU

                         L      AAA   N   N  TTTTT   OOO   SSSS
                         L     A   A  N   N    T    O   O S
                         L     A   A  NN  N    T    O   O S
                         L     A   A  N N N    T    O   O  SSS
                         L     AAAAA  N  NN    T    O   O     S
                         L     A   A  N   N    T    O   O     S
                         LLLLL A   A  N   N    T     OOO  SSSS

                 SSSSSSSS   IIIIII   MM      MM  UU      UU  LL
                 SSSSSSSS   IIIIII   MM      MM  UU      UU  LL
                SS            II     MMMM  MMMM  UU      UU  LL
                SS            II     MMMM  MMMM  UU      UU  LL
                SS            II     MM  MM  MM  UU      UU  LL
                SS            II     MM  MM  MM  UU      UU  LL
                 SSSSSS       II     MM      MM  UU      UU  LL
                 SSSSSS       II     MM      MM  UU      UU  LL
                       SS     II     MM      MM  UU      UU  LL
                       SS     II     MM      MM  UU      UU  LL
                       SS     II     MM      MM  UU      UU  LL
                       SS     II     MM      MM  UU      UU  LL
                SSSSSSSS    IIIIII   MM      MM  UUUUUUUUUU  LLLLLLLLLL
                SSSSSSSS    IIIIII   MM      MM  UUUUUUUUUU  LLLLLLLLLL

                     OOOOOO    UU      UU  TTTTTTTTTT         ;;;;       222222
                     OOOOOO    UU      UU  TTTTTTTTTT         ;;;;       222222
                   OO      OO  UU      UU      TT             ;;;;     22      22
                   OO      OO  UU      UU      TT             ;;;;     22      22
                   OO      OO  UU      UU      TT                              22
                   OO      OO  UU      UU      TT                              22
                   OO      OO  UU      UU      TT             ;;;;           22
                   OO      OO  UU      UU      TT             ;;;;           22
                   OO      OO  UU      UU      TT             ;;;;         22
                   OO      OO  UU      UU      TT             ;;;;         22
           ....    OO      OO  UU      UU      TT               ;;       22
           ....    OO      OO  UU      UU      TT               ;;       22
           ....      OOOOOO    UUUUUUUUUU      TT             ;;       2222222222
           ....      OOOOOO    UUUUUUUUUU      TT             ;;       2222222222


File _DUA1:[LANTOS]SIMUL.OUT;2 (1413,66,0), last revised on 28-SEP-1988 10:38, is a 28 block sequential file owned by UIC
[GANDM,LANTOS].  The records are variable length with FORTRAN (FTN) carriage control.  The longest record is 116 bytes.

Job SIMUL (226) queued to SYS$PRINT on 28-SEP-1988 10:52 by user LANTOS, UIC [GANDM,LANTOS], under account GANDM at priority 100,
started on printer _TXA3: on 28-SEP-1988 11:05 from queue SYS$PRINT.

UUUUUUUUUU     0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000     UUUUUUUUUU
UUUUUUUUUU     0000000000000000000000000  Digital Equipment Corporation - VAX/VMS Version V4.6  0000000000000000000000000     UUUUUUUUUU
UUUUUUUUUU     0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000     UUUUUUUUUU
```

```
                                    INPUT DATA
                             TURNING CIRCLE MANOEUVRE
**********************************************************************************
                  DESCRIPTION                            VALUE              UNITS
----------------------------------------------------------------------------------
LENGTH BETWEEN PERPENDICULARS                           218. 80            METERS
LENGTH ON WATERLINE                                     218. 80            METERS
BREADTH                                                  23. 12            METERS
DRAFT AFT                                                 6. 71            METERS
DRAFT FWD                                                 3. 35            METERS
DISPLACEMENT                                          21900. 00            TONNES
BLOCK COEFFICIENT                                         0. 88            -----
MIDSHIP SECTION COEFFICIENT                               1. 00            -----
WATERPLANE COEFFICIENT                                    0. 91            -----
RUDDER LATERAL AREA                                      25. 1             SQ. METERS
PROPELLER DIAMETER                                        5. 70            METERS
PROPELLER PITCH/DIAMETER RATIO                            0. 96            -----
PROPELLER EXPANDED BLADE AREA RATIO                       0. 50            -----
SHAFT HORSEPOWER                                       5400. 0              KW
**********************************************************************************
                            SHIP SPEED - POWER DATA
 SPEED     WAVE       APPEND     BULB BOW    TRANSOM      CORR.     FRICTION     TOTAL      EFFECTIVE
           RESIST     RESIST      RESIST      RESIST      RESIST      RESIST      RESIST     HORSEPOWER
(KNOTS)     (KN)       (KN)        (KN)        (KN)        (KN)        (KN)        (KN)        (KW)
*****************************************************************************************************
  10. 0  0. 149E+02  0. 332E+01  0. 597E+00  0. 000E+00  0. 448E+02  0. 129E+03  0. 229E+03  0. 118E+04
  11. 0  0. 309E+02  0. 400E+01  0. 673E+00  0. 000E+00  0. 542E+02  0. 155E+03  0. 288E+03  0. 163E+04
  12. 0  0. 569E+02  0. 473E+01  0. 744E+00  0. 000E+00  0. 645E+02  0. 182E+03  0. 360E+03  0. 222E+04
  13. 0  0. 960E+02  0. 553E+01  0. 811E+00  0. 000E+00  0. 757E+02  0. 212E+03  0. 449E+03  0. 300E+04
  14. 0  0. 151E+03  0. 639E+01  0. 872E+00  0. 000E+00  0. 877E+02  0. 243E+03  0. 557E+03  0. 402E+04
  15. 0  0. 224E+03  0. 731E+01  0. 928E+00  0. 000E+00  0. 101E+03  0. 277E+03  0. 687E+03  0. 530E+04
  16. 0  0. 316E+03  0. 829E+01  0. 980E+00  0. 000E+00  0. 115E+03  0. 313E+03  0. 841E+03  0. 692E+04
```

```
   17.0   0.431E+03  0.933E+01  0.103E+01  0.000E+00  0.129E+03  0.350E+03  0.102E+04   0.891E+04
   18.0   0.567E+03  0.104E+02  0.107E+01  0.000E+00  0.145E+03  0.390E+03  0.122E+04   0.113E+05
   19.0   0.728E+03  0.116E+02  0.111E+01  0.000E+00  0.162E+03  0.432E+03  0.146E+04   0.142E+05
   20.0   0.908E+03  0.128E+02  0.115E+01  0.000E+00  0.179E+03  0.476E+03  0.171E+04   0.176E+05
 WAKE FRACTION =  0.450
 THRUST DEDUCTION FRACTION =  0.160
 FORM FACTOR OF THE HULL =  0.281
 The friction resistance in the above table was
 multiplied by (1.+CFORM) to obtain the total
 resistance.
 ***************************************************************************************************************
  TIME       LOCAL        LOCAL        LOCAL          GLOBAL         GLOBAL      YAW ANGLE   ROLL ANGLE   PROPELLER
            X-SPEED      Y-SPEED    SHIP SPEED     X-POSITION     Y-POSITION                              SPEED
 (SECS)     (KNOTS)      (KNOTS)     (KNOTS)        (METERS)       (METERS)    (DEGREES)    (DEGREES)      (RPM)
 ***************************************************************************************************************
    0.0      12.50         0.00       12.50            0.00           0.00          0.0          0.0       120.0
   10.0      12.96         0.36       12.96           65.60           0.34         -0.8         -0.1       120.5
   20.0      13.00         1.31       13.06          132.65           1.25         -5.6          0.0       120.9
   30.0      12.84         2.07       13.01          199.72          -0.68        -13.1          0.1       120.6
   40.0      12.60         2.50       12.84          265.72          -8.74        -21.4          0.2       120.2
   50.0      12.32         2.72       12.62          329.31         -24.32        -29.9          0.2       119.9
   60.0      12.05         2.82       12.37          389.18         -47.60        -38.3          0.2       119.6
   70.0      11.78         2.87       12.13          444.22         -78.17        -46.7          0.2       119.3
   80.0      11.54         2.88       11.89          493.52        -115.29        -55.0          0.2       119.0
   90.0      11.31         2.87       11.67          536.36        -158.07        -63.2          0.2       118.8
  100.0      11.10         2.86       11.46          572.17        -205.52        -71.4          0.2       118.6
  110.0      10.91         2.85       11.28          600.53        -256.62        -79.6          0.2       118.4
  120.0      10.74         2.84       11.10          621.18        -310.29        -87.8          0.2       118.2
  130.0      10.58         2.82       10.95          633.98        -365.49        -95.9          0.2       118.0
  140.0      10.43         2.81       10.80          638.93        -421.16       -104.0          0.2       117.9
  150.0      10.30         2.79       10.67          636.17        -476.26       -112.0          0.2       117.7
  1            17         2.            55             .9             82        -1            0          17.
 170.0    10.06     2.77    10.44      608.61    -580.89    -128.1      0.2     117.5
 180.0     9.96     2.76    10.34      584.65    -628.60    -136.1      0.2     117.4
 190.0     9.87     2.75    10.24      554.64    -672.15    -144.1      0.2     117.3
 200.0     9.78     2.74    10.16      519.23    -710.82    -152.1      0.2     117.2
 210.0     9.70     2.74    10.08      479.17    -744.00    -160.1      0.2     117.2
 220.0     9.63     2.73    10.01      435.26    -771.16    -168.0      0.2     117.1
 230.0     9.56     2.72     9.94      388.37    -791.91    -176.0      0.2     117.0
 240.0     9.50     2.71     9.88      339.38    -805.95    -183.9      0.2     117.0
 250.0     9.45     2.71     9.83      289.23    -813.10    -191.8      0.2     116.9
 260.0     9.40     2.70     9.78      238.84    -813.33    -199.7      0.2     116.9
 270.0     9.35     2.70     9.73      189.15    -806.70    -207.6      0.2     116.8
 280.0     9.31     2.69     9.69      141.04    -793.40    -215.5      0.2     116.8
 290.0     9.27     2.69     9.65       95.40    -773.73    -223.4      0.2     116.7
 300.0     9.23     2.69     9.61       53.03    -748.12    -231.3      0.2     116.7
 310.0     9.20     2.68     9.58       14.70    -717.08    -239.2      0.2     116.7
 320.0     9.17     2.68     9.55      -18.93    -681.22    -247.1      0.2     116.6
 330.0     9.14     2.68     9.52      -47.27    -641.22    -254.9      0.2     116.6
 340.0     9.11     2.67     9.50      -69.82    -597.86    -262.8      0.2     116.6
 350.0     9.09     2.67     9.47      -86.21    -551.95    -270.7      0.2     116.6
 360.0     9.07     2.67     9.45      -96.16    -504.35    -278.5      0.2     116.5
 370.0     9.05     2.67     9.43      -99.53    -455.94    -286.4      0.2     116.5
 380.0     9.03     2.66     9.41      -96.28    -407.62    -294.2      0.2     116.5
 390.0     9.01     2.66     9.39      -86.49    -360.29    -302.1      0.2     116.5
 400.0     8.99     2.66     9.38      -70.38    -314.81    -309.9      0.2     116.5
 410.0     8.98     2.66     9.36      -48.26    -272.01    -317.7      0.2     116.4
 420.0     8.97     2.66     9.35      -20.56    -232.68    -325.6      0.2     116.4
 430.0     8.95     2.66     9.34       12.19    -197.54    -333.4      0.2     116.4
 440.0     8.94     2.66     9.33       49.38    -167.22    -341.3      0.2     116.4
 450.0     8.93     2.65     9.32       90.29    -142.27    -349.1      0.2     116.4
 460.0     8.92     2.65     9.31      134.18    -123.15    -356.9      0.2     116.4
```

```
   470.0      8.91      2.65      9.30      180.22     -110.18     -364.8      0.2      116.4
   480.0      8.91      2.65      9.29      227.54     -103.61     -372.6      0.2      116.4
END OF TURNING CIRCLE MANOEUVRE

                          RESULTS FROM TIME SIMULATION ANALYSIS
                               TURNING CIRCLE MANOEUVRE
***************************************************************************************
                       DESCRIPTION                                 VALUE          UNITS
---------------------------------------------------------------------------------------
STEADY TURNING SPEED                                               9.30           KNOTS
NON-DIMENSIONAL ADVANCE (ADVANCE/LPP)                              2.86           -----
NON-DIMENSIONAL TRANSFER (TRANSFER/LPP)                            1.49           -----
NON-DIMENSIONAL TACTICAL DIAMETER (TAC. DIA./LPP)                  3.66           -----
NON-DIMENSIONAL STEADY TURNING DIAMETER (STDY. DIA./LPP)           3.13           -----
***************************************************************************************

                          RESULTS FROM THE EMPIRICAL ANALYSIS
                               TURNING CIRCLE MANOEUVRE
***************************************************************************************
                       DESCRIPTION                                 VALUE          UNITS
---------------------------------------------------------------------------------------
STEADY TURNING SPEED                                               5.97           KNOTS
NON-DIMENSIONAL ADVANCE (ADVANCE/LPP)                              3.63           -----
NON-DIMENSIONAL TRANSFER (TRANSFER/LPP)                            2.14           -----
NON-DIMENSIONAL TACTICAL DIAMETER (TAC. DIA./LPP)                  4.44           -----
NON-DIMENSIONAL STEADY TURNING DIAMETER (STDY. DIA./LPP)           3.92           -----
STANDARD DEVIATION OF (VST/VX1) = 0.185
STANDARD DEVIATION OF (ADV/LPP) = 0.162
STANDARD DEVIATION OF (TR/LPP) = 0.170
STANDARD DEVIATION OF (TACDIA/LPP) = 0.111
STA     D D     TION    (ST     A/LP     0.
MESSAGES FOR EMPIRICAL TURNING CIRCLE ANALYSIS
 ______________________________________________
 BLOCK COEFFICIENT IS OUTSIDE THE RANGE OF (. 56 <= CB <= . 87)
 RATIO (B/LPP) IS OUTSIDE THE RANGE OF (. 11 <= RATIO <= . 18)
******************************************************************************************************************

                                                  CRASH STOP MANOEUVRE
******************************************************************************************************************
                       DESCRIPTION                                       VALUE                        UNITS
__________________________________________________________________________________________________________________
 INITIAL SPEED OF SHIP                                                    12. 50                      KNOTS
 INITIAL RESISTANCE OF SHIP                                              404. 6                        KN
 MAXIMUM ASTERN THRUST                                                   326. 8                        KN
 NON-DIMENSIONAL HEAD REACH (REACH/LPP)                                    4. 36                      -----
******************************************************************************************************************
```

12

```
SSSSSSSSSS    9999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999    SSSSSSSSSS
SSSSSSSSSS    9999999999999999999999999  Digital Equipment Corporation - VAX/VMS Version V4.6  9999999999999999999999999    SSSSSSSSSS
SSSSSSSSSS    9999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999    SSSSSSSSSS

                                       L       AAA   N   N  TTTTT   OOO    SSSS
                                       L      A   A  N   N    T    O   O  S
                                       L      A   A  NN  N    T    O   O  S
                                       L      A   A  N N N    T    O   O   SSS
                                       L      AAAAA  N  NN    T    O   O      S
                                       L      A   A  N   N    T    O   O      S
                                       LLLLL  A   A  N   N    T     OOO   SSSS

  AAAAAA    LL            GGGGGGGG    OOOOOO    BBBBBBBB        11        000000    ZZZZZZZZZZ    IIIIII      GGGGGGGG
  AAAAAA    LL            GGGGGGGG    OOOOOO    BBBBBBBB        11        000000    ZZZZZZZZZZ    IIIIII      GGGGGGGG
AA      AA  LL          GG          OO      OO  BB      BB    1111      00      00          ZZ      II      GG
AA      AA  LL          GG          OO      OO  BB      BB    1111      00      00          ZZ      II      GG
AA      AA  LL          GG          OO      OO  BB      BB      11      00    0000        ZZ        II      GG
AA      AA  LL          GG          OO      OO  BB      BB      11      00    0000        ZZ        II      GG
AA      AA  LL          GG          OO      OO  BBBBBBBB        11      00  00  00      ZZ          II      GG
AA      AA  LL          GG          OO      OO  BBBBBBBB        11      00  00  00      ZZ          II      GG
AAAAAAAAAA  LL          GG  GGGGGG  OO      OO  BB      BB      11      0000    00    ZZ            II      GG  GGGGGG
AAAAAAAAAA  LL          GG  GGGGGG  OO      OO  BB      BB      11      0000    00    ZZ            II      GG  GGGGGG
AA      AA  LL          GG      GG  OO      OO  BB      BB      11      00      00  ZZ              II      GG      GG
AA      AA  LL          GG      GG  OO      OO  BB      BB      11      00      00  ZZ              II      GG      GG
AA      AA  LLLLLLLLLL    GGGGGG      OOOOOO    BBBBBBBB      111111      000000    ZZZZZZZZZZ    IIIIII      GGGGGG
AA      AA  LLLLLLLLLL    GGGGGG      OOOOOO    BBBBBBBB      111111      000000    ZZZZZZZZZZ    IIIIII      GGGGGG

                                    DDDDDDDD      AAAAAA    TTTTTTTTTT    ;;;;          11
                                    DDDDDDDD      AAAAAA    TTTTTTTTTT    ;;;;          11
                                    DD      DD  AA      AA      TT        ;;;;        1111
                                    DD      DD  AA      AA      TT        ;;;;        1111
                                    DD      DD  AA      AA      TT                      11
                                    DD      DD  AA      AA      TT                      11
                                    DD      DD  AA      AA      TT        ;;;;          11
                                    DD      DD  AA      AA      TT        ;;;;          11
                                    DD      DD  AAAAAAAAAA      TT        ;;;;          11
                                    DD      DD  AAAAAAAAAA      TT        ;;;;          11
                          ....      DD      DD  AA      AA      TT          ;;          11
                          ....      DD      DD  AA      AA      TT          ;;          11
                          ....      DDDDDDDD    AA      AA      TT        ;;        111111
                          ....      DDDDDDDD    AA      AA      TT        ;;        111111

File _DUA1:[LANTOS]ALGOB10ZIG.DAT;1 (1014,94,0), last revised on 29-JUL-1988 13:37, is a 1 block sequential file owned by UIC
[GANDM,LANTOS].  The records are variable length with implied (CR) carriage control.  The longest record is 62 bytes.

Job ALGOB-15SPIR (221) queued to SYS$PRINT on 28-SEP-1988 10:14 by user LANTOS, UIC [GANDM,LANTOS], under account GANDM at priority
100, started on printer _TXA3: on 28-SEP-1988 10:24 from queue SYS$PRINT.

SSSSSSSSSS    9999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999    SSSSSSSSSS
SSSSSSSSSS    9999999999999999999999999  Digital Equipment Corporation - VAX/VMS Version V4.6  9999999999999999999999999    SSSSSSSSSS
SSSSSSSSSS    9999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999    SSSSSSSSSS
```

```
1000.,1.14E-6,1,14.18,3.268E5
218.8,218.8,23.12,6.71,3.35,0.88,0.996,0.914,2.19E7
0.,0.,0.,0.,6.43,0.,0.,0.,2.,0.,0.,0.,0.,0.,0.45,0.
-110.,6.28,0.45,25.1,3.35,1.57,2.52,3.,0.,11,150.,0.,0,1,0.005
2.134,3.15,1.68,1
50.2,1.4
2,4000.,1.,10.,10,5.7,0.96,0.5,4,5.4E6,2
-108.4,7.93,6.43,1,1,3.15,1.,3,5.
```

24

```
TTTTTTTTTT    0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000    TTTTTTTTTT
TTTTTTTTTT    000000000000000000000000  Digital Equipment Corporation - VAX/VMS Version V4.6  000000000000000000000000    TTTTTTTTTT
TTTTTTTTTT    0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000    TTTTTTTTTT

                         L       AAA   N   N  TTTTT   000   SSSS
                         L      A   A  N   N    T    0   0 S
                         L      A   A  NN  N    T    0   0 S
                         L      A   A  N N N    T    0   0  SSS
                         L      AAAAA  N  NN    T    0   0     S
                         L      A   A  N   N    T    0   0     S
                         LLLLL  A   A  N   N    T     000  SSSS

                     SSSSSSSS    IIIIII    MM      MM  UU      UU  LL
                     SSSSSSSS    IIIIII    MM      MM  UU      UU  LL
                    SS             II      MMMM  MMMM  UU      UU  LL
                    SS             II      MMMM  MMMM  UU      UU  LL
                    SS             II      MM  MM  MM  UU      UU  LL
                    SS             II      MM  MM  MM  UU      UU  LL
                     SSSSSS        II      MM      MM  UU      UU  LL
                     SSSSSS        II      MM      MM  UU      UU  LL
                           SS      II      MM      MM  UU      UU  LL
                           SS      II      MM      MM  UU      UU  LL
                           SS      II      MM      MM  UU      UU  LL
                           SS      II      MM      MM  UU      UU  LL
                    SSSSSSSS     IIIIII    MM      MM  UUUUUUUUUU  LLLLLLLLLL
                    SSSSSSSS     IIIIII    MM      MM  UUUUUUUUUU  LLLLLLLLLL

                       000000    UU      UU  TTTTTTTTTT    ;;;;      333333
                       000000    UU      UU  TTTTTTTTTT    ;;;;      333333
                     00      00  UU      UU      TT        ;;;;    33      33
                     00      00  UU      UU      TT        ;;;;    33      33
                     00      00  UU      UU      TT                        33
                     00      00  UU      UU      TT                        33
                     00      00  UU      UU      TT        ;;;;          33
                     00      00  UU      UU      TT        ;;;;          33
                     00      00  UU      UU      TT        ;;;;            33
                     00      00  UU      UU      TT        ;;;;            33
                     00      00  UU      UU      TT          ;;    33      33
                     00      00  UU      UU      TT          ;;    33      33
                       000000    UUUUUUUUUU      TT        ;;        333333
                       000000    UUUUUUUUUU      TT        ;;        333333

File _DUA1:[LANTOS]SIMUL.OUT;3 (1420,67,0), last revised on 28-SEP-1988 10:38, is a 22 block sequential file owned by UIC
[GANDM,LANTOS].  The records are variable length with FORTRAN (FTN) carriage control.  The longest record is 116 bytes.

Job SIMUL (226) queued to SYS$PRINT on 28-SEP-1988 10:52 by user LANTOS, UIC [GANDM,LANTOS], under account GANDM at priority 100,
started on printer _TXA3: on 28-SEP-1988 11:04 from queue SYS$PRINT.

TTTTTTTTTT    0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000    TTTTTTTTTT
TTTTTTTTTT    000000000000000000000000  Digital Equipment Corporation - VAX/VMS Version V4.6  000000000000000000000000    TTTTTTTTTT
TTTTTTTTTT    0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000    TTTTTTTTTT
TTTTTTTTTT    0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000     TTTTTTTTTT
TTTTTTTTTT    0000000000000000000000000  Digital Equipment Corporation - VAX/VMS Version V4.6  0000000000000000000000000     TTTTTTTTTT
TTTTTTTTTT    0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000     TTTTTTTTTT

                                               L       AAA  N   N  TTTTT  OOO    SSSS
                                               L      A   A N   N    T   O   O  S
                                               L      A   A NN  N    T   O   O  S
                                               L      A   A N N N    T   O   O   SSS
                                               L      AAAAA N  NN    T   O   O      S
                                               L      A   A N   N    T   O   O      S
                                               LLLLL  A   A N   N    T    OOO   SSSS

                                        SSSSSSSS    IIIIII    MM      MM  UU      UU  LL
                                        SSSSSSSS    IIIIII    MM      MM  UU      UU  LL
                                      SS              II      MMMM  MMMM  UU      UU  LL
                                      SS              II      MMMM  MMMM  UU      UU  LL
                                      SS              II      MM  MM  MM  UU      UU  LL
                                      SS              II      MM  MM  MM  UU      UU  LL
                                        SSSSSS        II      MM      MM  UU      UU  LL
                                        SSSSSS        II      MM      MM  UU      UU  LL
                                              SS      II      MM      MM  UU      UU  LL
                                              SS      II      MM      MM  UU      UU  LL
                                              SS      II      MM      MM  UU      UU  LL
                                              SS      II      MM      MM  UU      UU  LL
                                      SSSSSSSS      IIIIII    MM      MM  UUUUUUUUUU  LLLLLLLLLL
                                      SSSSSSSS      IIIIII    MM      MM  UUUUUUUUUU  LLLLLLLLLL

                                              OOOOOO    UU      UU  TTTTTTTTTT       ;;;;      333333
                                              OOOOOO    UU      UU  TTTTTTTTTT       ;;;;      333333
                                            OO      OO  UU      UU      TT           ;;;;    33      33
                                            OO      OO  UU      UU      TT           ;;;;    33      33
                                            OO      OO  UU      UU      TT                           33
                                            OO      OO  UU      UU      TT                           33
                                            OO      OO  UU      UU      TT           ;;;;          33
                                            OO      OO  UU      UU      TT           ;;;;          33
                                            OO      OO  UU      UU      TT           ;;;;            33
                                            OO      OO  UU      UU      TT           ;;;;            33
                                            OO      OO  UU      UU      TT             ;;    33      33
                                            OO      OO  UU      UU      TT             ;;    33      33
                                              OOOOOO    UUUUUUUUUU      TT           ;;        333333
                                              OOOOOO    UUUUUUUUUU      TT           ;;        333333

File  DUA1:[LANTOS]SIMUL.OUT;3 (1420,67,0), last revised on 28-SEP-1988 10:38, is a 22 block sequential file owned by UIC
[QANDM,LANTOS].  The records are variable length with FORTRAN (FTN) carriage control.  The longest record is 116 bytes.

Job SIMUL (226) queued to SYS$PRINT on 28-SEP-1988 10:52 by user LANTOS, UIC [QANDM,LANTOS], under account QANDM at priority 100,
started on printer _TXA3: on 28-SEP-1988 11:04 from queue SYS$PRINT.

TTTTTTTTTT    0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000     TTTTTTTTTT
TTTTTTTTTT    0000000000000000000000000  Digital Equipment Corporation - VAX/VMS Version V4.6  0000000000000000000000000     TTTTTTTTTT
TTTTTTTTTT    0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000     TTTTTTTTTT
```

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```
                                  INPUT DATA
                               ZIGZAG MANOEUVRE
****************************************************************************************
                       DESCRIPTION                               VALUE            UNITS
----------------------------------------------------------------------------------------
 LENGTH BETWEEN PERPENDICULARS                                  218.80           METERS
 LENGTH ON WATERLINE                                            218.80           METERS
 BREADTH                                                         23.12           METERS
 DRAFT AFT                                                        6.71           METERS
 DRAFT FWD                                                        3.35           METERS
 DISPLACEMENT                                                 21900.00           TONNES
 BLOCK COEFFICIENT                                                0.88           -----
 MIDSHIP SECTION COEFFICIENT                                      1.00           -----
 WATERPLANE COEFFICIENT                                           0.91           -----
 RUDDER LATERAL AREA                                             25.1            SQ. METERS
 PROPELLER DIAMETER                                               5.70           METERS
 PROPELLER PITCH/DIAMETER RATIO                                   0.96           -----
 PROPELLER EXPANDED BLADE AREA RATIO                              0.50           -----
 SHAFT HORSEPOWER                                              5400.0              KW
****************************************************************************************
                            SHIP SPEED - POWER DATA
 SPEED     WAVE       APPEND     BULB BOW    TRANSOM     CORR.      FRICTION    TOTAL      EFFECTIVE
          RESIST      RESIST      RESIST      RESIST     RESIST      RESIST     RESIST     HORSEPOWER
 (KNOTS)   (KN)        (KN)        (KN)        (KN)       (KN)        (KN)       (KN)        (KW)
****************************************************************************************
 10.0   0.149E+02  0.332E+01  0.597E+00  0.000E+00  0.448E+02  0.129E+03  0.229E+03  0.118E+04
 11.0   0.309E+02  0.400E+01  0.673E+00  0.000E+00  0.542E+02  0.155E+03  0.288E+03  0.163E+04
 12.0   0.569E+02  0.473E+01  0.744E+00  0.000E+00  0.645E+02  0.182E+03  0.360E+03  0.222E+04
 13.0   0.960E+02  0.553E+01  0.811E+00  0.000E+00  0.757E+02  0.212E+03  0.449E+03  0.300E+04
 14.0   0.151E+03  0.639E+01  0.872E+00  0.000E+00  0.877E+02  0.243E+03  0.557E+03  0.402E+04
 15.0   0.224E+03  0.731E+01  0.928E+00  0.000E+00  0.101E+03  0.277E+03  [redacted]  [redacted]
 16.[redacted]  0.[redacted]+03  [redacted]829[redacted]  0[redacted]E+0[redacted]  [redacted]0.00[redacted]0  [redacted]15E+03  0.[redacted]E+03  0.841E+03  0.692E+04
```

```
  17.0   0.431E+03  0.933E+01  0.103E+01  0.000E+00  0.129E+03  0.350E+03  0.102E+04   0.891E+04
  18.0   0.567E+03  0.104E+02  0.107E+01  0.000E+00  0.145E+03  0.390E+03  0.122E+04   0.113E+05
  19.0   0.728E+03  0.116E+02  0.111E+01  0.000E+00  0.162E+03  0.432E+03  0.146E+04   0.142E+05
  20.0   0.908E+03  0.128E+02  0.115E+01  0.000E+00  0.179E+03  0.476E+03  0.171E+04   0.176E+05
 WAKE FRACTION =  0.450
 THRUST DEDUCTION FRACTION =  0.160
 FORM FACTOR OF THE HULL =  0.281
 The friction resistance in the above table was
 multiplied by (1.+CFORM) to obtain the total
 resistance.
 **********************************************************************************************
   TIME      LOCAL      LOCAL       LOCAL        GLOBAL       GLOBAL      YAW ANGLE  ROLL ANGLE  PROPELLER
            X-SPEED    Y-SPEED   SHIP SPEED   X-POSITION   Y-POSITION                             SPEED
  (SECS)    (KNOTS)    (KNOTS)    (KNOTS)      (METERS)     (METERS)    (DEGREES)   (DEGREES)     (RPM)
 **********************************************************************************************
     0.0     12.50       0.00      12.50          0.00         0.00        0.0         0.0        120.0
    10.0     13.00      -0.29      13.00         65.63        -0.30        0.8         0.0        120.5
    20.0     13.43      -0.74      13.45        133.70        -0.56        3.5         0.0        121.0
    30.0     13.81      -1.12      13.85        203.93         1.15        7.3        -0.1        121.4
    40.0     14.14      -1.30      14.20        275.88         6.52       11.4        -0.2        121.8
 RUDDER ANGLE IS  -10.00000

    50.0     14.50      -0.83      14.52        348.97        17.20       13.4        -0.1        122.3
    60.0     14.88      -0.17      14.88        423.18        31.78       12.5        -0.1        122.8
    70.0     15.22       0.47      15.22        498.98        47.65        9.8         0.0        123.1
    80.0     15.50       0.96      15.53        576.71        62.41        6.2         0.1        123.4
    90.0     15.72       1.29      15.77        656.38        74.10        2.1         0.1        123.6
   100.0     15.91       1.50      15.98        737.73        81.34       -2.1         0.1        123.8
   110.0     16.06       1.63      16.15        820.34        83.18       -6.5         0.2        124.0
   120.0     16.22       1.60      16.29        903.65        78.99      -10.8         0.3        124.2
 RUDDER ANGLE IS   10.00000

   130.0     16.43       0.96      16.46        987.17        68.10      -12.7         0.1        124.6
   140.0    16.68     0.12    16.68    1070.99    52.76   -11.4    0.1    125.0
   150.0    16.88    -0.63    16.89    1155.80    36.46    -8.3    0.0    125.1
   160.0    17.02    -1.16    17.06    1241.97    22.20    -4.2   -0.1    125.2
   170.0    17.11    -1.49    17.17    1329.45    12.19     0.2   -0.1    125.3
   180.0    17.17    -1.68    17.25    1417.88     7.88     4.9   -0.2    125.3
   190.0    17.20    -1.79    17.30    1506.70    10.07     9.6   -0.2    125.4
 RUDDER ANGLE IS  -10.00000

   200.0    17.31    -1.34    17.36    1595.31    19.63    13.0   -0.2    125.6
   210.0    17.48    -0.51    17.49    1683.51    35.41    12.9   -0.1    125.9
   220.0    17.65     0.30    17.65    1772.05    53.58    10.6    0.0    126.1
   230.0    17.76     0.91    17.78    1861.55    70.90     7.1    0.1    126.1
   240.0    17.82     1.31    17.87    1952.20    84.84     3.0    0.1    126.1
   250.0    17.85     1.55    17.92    2043.82    93.68    -1.3    0.2    126.2
   260.0    17.86     1.69    17.94    2136.00    96.39    -5.8    0.2    126.2
   270.0    17.86     1.70    17.94    2228.18    92.36   -10.3    0.2    126.2
 RUDDER ANGLE IS   10.00000

   280.0    17.94     1.13    17.98    2319.82    80.92   -12.8    0.2    126.4
   290.0    18.07     0.23    18.07    2410.98    64.11   -11.9    0.1    126.7
   300.0    18.17    -0.60    18.18    2502.46    46.00    -8.9    0.0    126.7
   310.0    18.21    -1.17    18.25    2594.82    29.99    -4.9   -0.1    126.7
   320.0    18.21    -1.52    18.27    2688.08    18.59    -0.4   -0.2    126.6
   330.0    18.18    -1.72    18.26    2781.90    13.31     4.3   -0.2    126.6
   340.0    18.14    -1.83    18.23    2875.73    15.00     9.0   -0.2    126.5
 END OF ZIGZAG SIMULATION

                          RESULTS FROM TIME SIMULATION ANALYSIS
                                    ZIGZAG MANOEUVRE
 ************************************************************************************
                  DESCRIPTION                            VALUE                 UNITS
```

```
OVERSHOOT ANGLE                                                  3.39            DEGREES
NON-DIMENSIONAL OVERSHOOT WIDTH OF PATH (WIDTH/LPP)              0.36            -----
PERIOD BETWEEN 1st RUDDER CHANGE AND 3rd RUDDER CHANGE         154.0             SECS.
NON-DIMENSIONAL REACH (REACH/LPP)                                3.22            -----
******************************************************************************************

                         RESULTS FROM THE EMPIRICAL ANALYSIS

                              CRASH STOP MANOEUVRE
******************************************************************************************
              DESCRIPTION                                      VALUE             UNITS
------------------------------------------------------------------------------------------
INITIAL SPEED OF SHIP                                           12.50            KNOTS
INITIAL RESISTANCE OF SHIP                                     404.6              KN
MAXIMUM ASTERN THRUST                                          326.8              KN
NON-DIMENSIONAL HEAD REACH (REACH/LPP)                           4.36            -----
******************************************************************************************
```

```
TTTTTTTTTT   9999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999   TTTTTTTTTT
TTTTTTTTTT   99999999999999999999999999  Digital Equipment Corporation - VAX/VMS Version V4.6  99999999999999999999999999   TTTTTTTTTT
TTTTTTTTTT   9999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999   TTTTTTTTTT

                                  L      AAA   N   N  TTTTT  OOO   SSSS
                                  L     A   A  N   N    T   O   O S
                                  L     A   A  NN  N    T   O   O S
                                  L     A   A  N N N    T   O   O  SSS
                                  L     AAAAA  N  NN    T   O   O     S
                                  L     A   A  N   N    T   O   O     S
                                  LLLLL A   A  N   N    T    OOO  SSSS

  AAAAAA     LL             QQQQQQQQ     OOOOOO     BBBBBBBB       222222       000000     ZZZZZZZZZZ   IIIIII     QQQQQQQQ
  AAAAAA     LL             QQQQQQQQ     OOOOOO     BBBBBBBB       222222       000000     ZZZZZZZZZZ   IIIIII     QQQQQQQQ
AA      AA   LL           QQ           OO      OO   BB      BB   22      22   00      00           ZZ     II     QQ
AA      AA   LL           QQ           OO      OO   BB      BB   22      22   00      00           ZZ     II     QQ
AA      AA   LL           QQ           OO      OO   BB      BB           22   00    0000         ZZ       II     QQ
AA      AA   LL           QQ           OO      OO   BB      BB           22   00    0000         ZZ       II     QQ
AA      AA   LL           QQ           OO      OO   BBBBBBBB         22     00  00  00       ZZ         II     QQ
AA      AA   LL           QQ           OO      OO   BBBBBBBB         22     00  00  00       ZZ         II     QQ
AAAAAAAAAA   LL           QQ  QQQQQQ   OO      OO   BB      BB       22       0000    00     ZZ           II     QQ  QQQQQQ
AAAAAAAAAA   LL           QQ  QQQQQQ   OO      OO   BB      BB       22       0000    00     ZZ           II     QQ  QQQQQQ
AA      AA   LL           QQ      QQ   OO      OO   BB      BB     22         00      00   ZZ             II     QQ      QQ
AA      AA   LL           QQ      QQ   OO      OO   BB      BB     22         00      00   ZZ             II     QQ      QQ
AA      AA   LLLLLLLLLL     QQQQQQ       OOOOOO     BBBBBBBB     2222222222     000000     ZZZZZZZZZZ   IIIIII     QQQQQQ
AA      AA   LLLLLLLLLL     QQQQQQ       OOOOOO     BBBBBBBB     2222222222     000000     ZZZZZZZZZZ   IIIIII     QQQQQQ

                                       DDDDDDDD     AAAAAA     TTTTTTTTTT   ;;;;     11
                                       DDDDDDDD     AAAAAA     TTTTTTTTTT   ;;;;     11
                                       DD      DD   AA      AA       TT       ;;;;   1111
                                       DD      DD   AA      AA       TT       ;;;;   1111
                                       DD      DD   AA      AA       TT                 11
                                       DD      DD   AA      AA       TT                 11
                                       DD      DD   AA      AA       TT       ;;;;     11
                                       DD      DD   AA      AA       TT       ;;;;     11
                                       DD      DD   AAAAAAAAAA       TT       ;;;;     11
                                       DD      DD   AAAAAAAAAA       TT       ;;;;     11
                           . . . .     DD      DD   AA      AA       TT         ;;     11
                           . . . .     DD      DD   AA      AA       TT         ;;     11
                           . . . .     DDDDDDDD     AA      AA       TT       ;;       111111
                           . . . .     DDDDDDDD     AA      AA       TT       ;;       111111

File _DUA1:[LANTOS]ALQOB20ZIQ.DAT;1 (1112,48,0), last revised on 29-JUL-1988 13:37, is a 1 block sequential file owned by UIC
[QANDM,LANTOS].  The records are variable length with implied (CR) carriage control.  The longest record is 62 bytes.

Job ALQOB-13SPIR (221) queued to SYS$PRINT on 28-SEP-1988 10:14 by user LANTOS, UIC [QANDM,LANTOS], under account QANDM at priority
100, started on printer _TXA3: on 28-SEP-1988 10:24 from queue SYS$PRINT.

TTTTTTTTTT   9999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999   TTTTTTTTTT
TTTTTTTTTT   99999999999999999999999999  Digital Equipment Corporation - VAX/VMS Version V4.6  99999999999999999999999999   TTTTTTTTTT
TTTTTTTTTT   9999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999   TTTTTTTTTT
```

```
1000. , 1. 14E-6, 1, 14. 18, 3. 268E5
218. 8, 218. 8, 23. 12, 6. 71, 3. 35, 0. 88, 0. 996, 0. 914, 2. 19E7
0. , 0. , 0. , 0. , 6. 43, 0. , 0. , 0. , 2. , 0. , 0. , 0. , 0. , 0. , 0. 45, 0.
-110. , 6. 28, 0. 45, 25. 1, 3. 35, 1. 57, 2. 52, 3. , 0. , 11, 150. , 0. , 0, 1, 0. 005
2. 134, 3. 15, 1. 68, 1
50. 2, 1. 4
2, 4000. , 1. , 20. , 10, 5. 7, 0. 96, 0. 5, 4, 5. 4E6, 2
-108. 4, 7. 93, 6. 43, 1, 1, 3. 15, 1. , 3, 5.
```

```
SSSSSSSSSS   0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
SSSSSSSSSS   000000000000000000000000  Digital Equipment Corporation - VAX/VMS Version V4.6  0000000000000000000000000   SSSSSSSSSS
SSSSSSSSSS   0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000   SSSSSSSSSS
                                                                                                                  SSSSSSSSSS

                          L       AAA    N   N  TTTTT   OOO   SSSS
                          L      A   A   N   N    T    O   O  S
                          L      A   A   NN  N    T    O   O  S
                          L      A   A   N N N    T    O   O   SSS
                          L      AAAAA   N  NN    T    O   O      S
                          L      A   A   N   N    T    O   O      S
                          LLLLL  A   A   N   N    T     OOO   SSSS

                       SSSSSSSS   IIIIII   MM      MM  UU      UU  LL
                       SSSSSSSS   IIIIII   MM      MM  UU      UU  LL
                     SS             II     MMMM  MMMM  UU      UU  LL
                     SS             II     MMMM  MMMM  UU      UU  LL
                     SS             II     MM  MM  MM  UU      UU  LL
                     SS             II     MM  MM  MM  UU      UU  LL
                       SSSSSS       II     MM      MM  UU      UU  LL
                       SSSSSS       II     MM      MM  UU      UU  LL
                             SS     II     MM      MM  UU      UU  LL
                             SS     II     MM      MM  UU      UU  LL
                             SS     II     MM      MM  UU      UU  LL
                             SS     II     MM      MM  UU      UU  LL
                     SSSSSSSS     IIIIII   MM      MM  UUUUUUUUUU  LLLLLLLLLL
                     SSSSSSSS     IIIIII   MM      MM  UUUUUUUUUU  LLLLLLLLLL

                             000000    UU      UU  TTTTTTTTTT      ;;;;    44      44
                             000000    UU      UU  TTTTTTTTTT      ;;;;    44      44
                           00      00  UU      UU      TT          ;;;;    44      44
                           00      00  UU      UU      TT                  44      44
                           00      00  UU      UU      TT                  44      44
                           00      00  UU      UU      TT                  44      44
                           00      00  UU      UU      TT          ;;;;    4444444444
                           00      00  UU      UU      TT          ;;;;    4444444444
                           00      00  UU      UU      TT          ;;;;            44
                     ....  00      00  UU      UU      TT            ;;            44
                     ....    000000    UUUUUUUUUU      TT            ;;            44
                     ....    000000    UUUUUUUUUU      TT          ;;              44

File _DUA1:[LANTOS]SIMUL.OUT;4 (1426,111,0), last revised on 28-SEP-1988 10:39, is a 24 block sequential file owned by UIC
[QANDM,LANTOS].  The records are variable length with FORTRAN (FTN) carriage control.  The longest record is 116 bytes.

Job SIMUL (226) queued to SYS$PRINT on 28-SEP-1988 10:52 by user LANTOS, UIC [QANDM,LANTOS], under account QANDM at priority 100,
started on printer _TXA3: on 28-SEP-1988 11:04 from queue SYS$PRINT.

SSSSSSSSSS   0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000   SSSSSSSSSS
SSSSSSSSSS   000000000000000000000000  Digital Equipment Corporation - VAX/VMS Version V4.6  0000000000000000000000000   SSSSSSSSSS
SSSSSSSSSS   0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000   SSSSSSSSSS
```

2

```
                                     INPUT DATA
                                  ZIGZAG MANOEUVRE
*****************************************************************************************************
                   DESCRIPTION                                     VALUE                UNITS
-----------------------------------------------------------------------------------------------------
 LENGTH BETWEEN PERPENDICULARS
 LENGTH ON WATERLINE                                               218.80               METERS
 BREADTH                                                           218.80               METERS
 DRAFT AFT                                                          23.12               METERS
 DRAFT FWD                                                           6.71               METERS
 DISPLACEMENT                                                        3.35               METERS
 BLOCK COEFFICIENT                                               21900.00               TONNES
 MIDSHIP SECTION COEFFICIENT                                         0.88               -----
 WATERPLANE COEFFICIENT                                              1.00               -----
 RUDDER LATERAL AREA                                                 0.91               -----
 PROPELLER DIAMETER                                                 25.1                SQ. METERS
 PROPELLER PITCH/DIAMETER RATIO                                      5.70               METERS
 PROPELLER EXPANDED BLADE AREA RATIO                                 0.96               -----
 SHAFT HORSEPOWER                                                    0.50               -----
                                                                  5400.0                KW
*****************************************************************************************************
                              SHIP SPEED - POWER DATA
 SPEED     WAVE       APPEND     BULB BOW    TRANSOM     CORR.      FRICTION     TOTAL     EFFECTIVE
(KNOTS)   RESIST     RESIST      RESIST      RESIST     RESIST      RESIST      RESIST    HORSEPOWER
           (KN)       (KN)        (KN)        (KN)       (KN)        (KN)        (KN)        (KW)
*****************************************************************************************************
 10.0   0.149E+02  0.332E+01  0.597E+00  0.000E+00  0.448E+02  0.129E+03  0.229E+03  0.118E+04
 11.0   0.309E+02  0.400E+01  0.673E+00  0.000E+00  0.542E+02  0.155E+03  0.288E+03  0.163E+04
 12.0   0.569E+02  0.473E+01  0.744E+00  0.000E+00  0.645E+02  0.182E+03  0.360E+03  0.222E+04
 13.0   0.960E+02  0.553E+01  0.811E+00  0.000E+00  0.757E+02  0.212E+03  0.449E+03  0.300E+04
 14.0   0.151E+03  0.639E+01  0.872E+00  0.000E+00  0.877E+02  0.243E+03  0.557E+03  0.402E+04
 15.0   0.224E+03  0.731E+01  0.928E+00  0.000E+00  0.101E+03  0.277E+03  0.687E+03  0.530E+04
 16.0   0.316E+03  0.829E+01  0.980E+00  0.000E+00  0.115E+03  0.313E+03  0.841E+03  0.692E+04
```

```
17.0    0.431E+03   0.933E+01   0.103E+01   0.000E+00   0.129E+03   0.350E+03   0.102E+04   0.891E+04
18.0    0.567E+03   0.104E+02   0.107E+01   0.000E+00   0.145E+03   0.390E+03   0.122E+04   0.113E+05
19.0    0.728E+03   0.116E+02   0.111E+01   0.000E+00   0.162E+03   0.432E+03   0.146E+04   0.142E+05
20.0    0.908E+03   0.128E+02   0.115E+01   0.000E+00   0.179E+03   0.476E+03   0.171E+04   0.176E+05
WAKE FRACTION =  0.450
THRUST DEDUCTION FRACTION =  0.160
FORM FACTOR OF THE HULL =  0.281
The friction resistance in the above table was
multiplied by (1.+CFORM) to obtain the total
resistance.
*****************************************************************************************************************
  TIME      LOCAL       LOCAL         LOCAL         GLOBAL         GLOBAL      YAW ANGLE   ROLL ANGLE   PROPELLER
           X-SPEED     Y-SPEED     SHIP SPEED     X-POSITION     Y-POSITION                              SPEED
  (SECS)   (KNOTS)     (KNOTS)      (KNOTS)        (METERS)       (METERS)     (DEGREES)   (DEGREES)     (RPM)
*****************************************************************************************************************
   0.0      12.50        0.00        12.50           0.00           0.00          0.0         0.0        120.0
  10.0      12.95       -0.40        12.96          65.59          -0.38          0.9         0.1        120.5
  20.0      13.22       -1.17        13.28         133.10          -1.03          5.3         0.0        121.0
  30.0      13.39       -1.76        13.50         201.96           1.31         11.5        -0.1        121.1
  40.0      13.47       -2.12        13.63         271.31           9.30         18.3        -0.2        121.1
  50.0      13.63       -2.06        13.79         340.06          24.59         24.6        -0.3        121.2
RUDDER ANGLE IS  -20.00000

  60.0      13.92       -1.24        13.98         407.46          48.19         27.2        -0.2        121.9
  70.0      14.22       -0.08        14.22         473.81          77.37         25.1        -0.1        122.4
  80.0      14.44        0.97        14.47         540.94         108.07         20.0         0.0        122.5
  90.0      14.55        1.66        14.64         610.27         136.45         13.8         0.1        122.4
 100.0      14.58        2.06        14.73         682.17         159.66          7.2         0.2        122.3
 110.0      14.58        2.27        14.75         756.21         175.93          0.5         0.2        122.3
 120.0      14.55        2.39        14.74         831.59         184.26         -6.2         0.2        122.3
 130.0      14.52        2.45        14.72         907.34         184.16        -12.9         0.2        122.2
 140.0   [illegible]48   2.[illegible]   [illegible]69   [illegible]2.45   [illegible]47   -[illegible]   0[illegible]   [illegible]22.[illegible]
```

```
   150.0    14.64     2.01     14.78     1055.99    157.77    -24.7     0.4     122.4
 RUDDER ANGLE IS   20.00000

   160.0    14.87     0.92     14.90     1127.80    131.92    -25.7     0.2     123.2
   170.0    15.08    -0.41     15.08     1198.69    101.58    -21.9     0.1     123.4
   180.0    15.17    -1.42     15.23     1270.71     71.59    -15.9    -0.1     123.2
   190.0    15.15    -2.01     15.28     1344.93     46.03     -9.0    -0.2     123.0
   200.0    15.07    -2.33     15.25     1421.22     27.48     -1.9    -0.2     122.9
   210.0    14.97    -2.49     15.17     1498.78     17.34      5.3    -0.2     122.8
   220.0    14.86    -2.56     15.08     1576.54     16.23     12.4    -0.2     122.6
   230.0    14.75    -2.60     14.98     1653.39     24.33     19.5    -0.2     122.5
   240.0    14.82    -2.27     14.99     1728.31     41.88     25.7    -0.3     122.6
 RUDDER ANGLE IS  -20.00000

   250.0    15.02    -1.25     15.07     1800.80     68.70     27.8    -0.2     123.3
   260.0    15.25     0.05     15.25     1871.76    100.95     25.0    -0.1     123.6
   270.0    15.38     1.12     15.42     1943.38    134.06     19.7     0.0     123.5
   280.0    15.40     1.79     15.50     2017.12    163.95     13.3     0.1     123.4
   290.0    15.36     2.16     15.51     2093.25    187.77      6.6     0.2     123.2
   300.0    15.28     2.35     15.46     2171.24    203.86     -0.2     0.2     123.1
   310.0    15.19     2.45     15.39     2250.20    211.37     -6.9     0.2     123.0
   320.0    15.10     2.50     15.31     2329.10    209.92    -13.7     0.2     122.9
   330.0    15.02     2.40     15.21     2406.89    199.44    -20.4     0.3     122.8
   340.0    15.17     1.95     15.30     2482.72    179.62    -25.3     0.3     123.1
 RUDDER ANGLE IS   20.00000

   350.0    15.36     0.77     15.38     2556.50    151.72    -25.7     0.2     123.8
   360.0    15.52    -0.58     15.54     2629.36    119.88    -21.6     0.1     123.9
   370.0    15.56    -1.54     15.64     2703.44     89.10    -15.3    -0.1     123.7
   380.0    15.50    -2.10     15.64     2779.71     63.42     -8.3    -0.2     123.4
   390.0    15.39    -2.38     15.57     2857.89     45.27     -1.2    -0.2     123.3
   400.0    15.25    -2.52     15.46     2937.13     35.90      6.0    -0.2     123.1
   410.0    15.12     -2.59     15.34     3016.31     35.85     13.1     -0.2     122.9
   420.0    14.99     -2.62     15.22     3094.31     45.21     20.2     -0.2     122.8
END OF ZIGZAG SIMULATION

                         RESULTS FROM TIME SIMULATION ANALYSIS
                                  ZIGZAG MANOEUVRE
******************************************************************************************
                  DESCRIPTION                                  VALUE             UNITS
------------------------------------------------------------------------------------------
 OVERSHOOT ANGLE                                                7.23            DEGREES
 NON-DIMENSIONAL OVERSHOOT WIDTH OF PATH (WIDTH/LPP)            0.79             -----
 PERIOD BETWEEN 1st RUDDER CHANGE AND 3rd RUDDER CHANGE       189.0              SECS.
 NON-DIMENSIONAL REACH (REACH/LPP)                              3.49             -----
******************************************************************************************

                           RESULTS FROM THE EMPIRICAL ANALYSIS

                                 CRASH STOP MANOEUVRE
******************************************************************************************
                  DESCRIPTION                                  VALUE             UNITS
------------------------------------------------------------------------------------------
 INITIAL SPEED OF SHIP                                         12.50             KNOTS
 INITIAL RESISTANCE OF SHIP                                   404.6               KN
 MAXIMUM ASTERN THRUST                                        326.8               KN
 NON-DIMENSIONAL HEAD REACH (REACH/LPP)                         4.36             -----
******************************************************************************************
```

```
UUUUUUUUUU     999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999
UUUUUUUUUU     99999999999999999999999999  Digital Equipment Corporation - VAX/VMS Version V4.6  99999999999999999999999999    UUUUUUUUUU
UUUUUUUUUU     999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999    UUUUUUUUUU
                                                                                                                               UUUUUUUUUU

                                                L       AAA   N   N  TTTTT   OOO    SSSS
                                                L      A   A  N   N    T    O   O  S
                                                L      A   A  NN  N    T    O   O  S
                                                L      A   A  N N N    T    O   O   SSS
                                                L      AAAAA  N  NN    T    O   O      S
                                                L      A   A  N   N    T    O   O      S
                                                LLLLL  A   A  N   N    T     OOO   SSSS

         AAAAAA    LL            GGGGGGGG    OOOOOO    BBBBBBBB      333333    5555555555    CCCCCCCC    IIIIII    RRRRRRRR
         AAAAAA    LL            GGGGGGGG    OOOOOO    BBBBBBBB      333333    5555555555    CCCCCCCC    IIIIII    RRRRRRRR
       AA      AA  LL          GG          OO      OO  BB      BB  33      33  55          CC              II      RR      RR
       AA      AA  LL          GG          OO      OO  BB      BB  33      33  55          CC              II      RR      RR
       AA      AA  LL          GG          OO      OO  BB      BB          33  555555      CC              II      RR      RR
       AA      AA  LL          GG          OO      OO  BB      BB          33  555555      CC              II      RR      RR
       AA      AA  LL          GG          OO      OO  BBBBBBBB          33          55    CC              II      RRRRRRRR
       AA      AA  LL          GG          OO      OO  BBBBBBBB          33          55    CC              II      RRRRRRRR
       AAAAAAAAAA  LL          GG  GGGGGG  OO      OO  BB      BB          33          55  CC              II      RR  RR
       AAAAAAAAAA  LL          GG  GGGGGG  OO      OO  BB      BB          33          55  CC              II      RR  RR
       AA      AA  LL          GG      GG  OO      OO  BB      BB  33      33  55      55  CC              II      RR    RR
       AA      AA  LL          GG      GG  OO      OO  BB      BB  33      33  55      55  CC              II      RR    RR
       AA      AA  LLLLLLLLLL    GGGGGG      OOOOOO    BBBBBBBB      333333      555555      CCCCCCCC    IIIIII    RR      RR
       AA      AA  LLLLLLLLLL    GGGGGG      OOOOOO    BBBBBBBB      333333      555555      CCCCCCCC    IIIIII    RR      RR

                                             DDDDDDDD      AAAAAA    TTTTTTTTTT      ;;;;         11
                                             DDDDDDDD      AAAAAA    TTTTTTTTTT      ;;;;         11
                                             DD      DD  AA      AA      TT          ;;;;       1111
                                             DD      DD  AA      AA      TT          ;;;;       1111
                                             DD      DD  AA      AA      TT                       11
                                             DD      DD  AA      AA      TT                       11
                                             DD      DD  AA      AA      TT          ;;;;         11
                                             DD      DD  AA      AA      TT          ;;;;         11
                                             DD      DD  AAAAAAAAAA      TT          ;;;;         11
                                             DD      DD  AAAAAAAAAA      TT          ;;;;         11
                                    ....     DD      DD  AA      AA      TT            ;;         11
                                    ....     DD      DD  AA      AA      TT            ;;         11
                                    ....     DDDDDDDD    AA      AA      TT          ;;         111111
                                    ....     DDDDDDDD    AA      AA      TT          ;;         111111

File  DUA1:[LANTOS]ALGOB35CIR.DAT;1 (1105,46,0), last revised on 29-JUL-1988 13:35, is a 1 block sequential file owned by UIC
[QANDM,LANTOS].  The records are variable length with implied (CR) carriage control.  The longest record is 62 bytes.

Job ALGOB-15SPIR (221) queued to SYS$PRINT on 28-SEP-1988 10:14 by user LANTOS, UIC [QANDM,LANTOS], under account QANDM at priority
100, started on printer _TXA3: on 28-SEP-1988 10:25 from queue SYS$PRINT.

UUUUUUUUUU     999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999
UUUUUUUUUU     99999999999999999999999999  Digital Equipment Corporation - VAX/VMS Version V4.6  99999999999999999999999999    UUUUUUUUUU
UUUUUUUUUU     999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999    UUUUUUUUUU
                                                                                                                               UUUUUUUUUU
```

```
1000.,1.14E-6,1,14.18,3.268E5
218.8,218.8,23.12,6.71,3.35,0.88,0.996,0.914,2.19E7
0.,0.,0.,0.,6.43,0.,0.,0.,2.,0.,0.,0.,0.,0.,0.45,0.
-110.,6.28,0.45,25.1,3.35,1.57,2.52,3.,0.,11,150.,0.,0,1,0.005
2.134,3.15,1.68,1
50.2,1.4
1,4000.,1.,35.,10,5.7,0.96,0.5,4,5.4E6,2
-108.4,7.93,6.43,1,1,3.15,1.,3,5.
```

```
RRRRRRRRRR   OOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOO   RRRRRRRRRR
RRRRRRRRRR   OOOOOOOOOOOOOOOOOOOOOOOOO  Digital Equipment Corporation - VAX/VMS Version V4.6  OOOOOOOOOOOOOOOOOOOOOOOOO   RRRRRRRRRR
RRRRRRRRRR   OOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOO   RRRRRRRRRR

                              L        AAA    N   N  TTTTT   OOO   SSSS
                              L       A   A   N   N    T    O   O S
                              L       A   A   NN  N    T    O   O S
                              L       A   A   N N N    T    O   O  SSS
                              L       AAAAA   N  NN    T    O   O     S
                              L       A   A   N   N    T    O   O     S
                              LLLLL   A   A   N   N    T     OOO  SSSS

                          SSSSSSSS    IIIIII    MM        MM  UU        UU  LL
                          SSSSSSSS    IIIIII    MM        MM  UU        UU  LL
                        SS              II      MMMM    MMMM  UU        UU  LL
                        SS              II      MMMM    MMMM  UU        UU  LL
                        SS              II      MM  MM  MM    UU        UU  LL
                        SS              II      MM  MM  MM    UU        UU  LL
                          SSSSSS        II      MM        MM  UU        UU  LL
                          SSSSSS        II      MM        MM  UU        UU  LL
                                SS      II      MM        MM  UU        UU  LL
                                SS      II      MM        MM  UU        UU  LL
                                SS      II      MM        MM  UU        UU  LL
                                SS      II      MM        MM  UU        UU  LL
                        SSSSSSSS      IIIIII    MM        MM  UUUUUUUUUU  LLLLLLLLLL
                        SSSSSSSS      IIIIII    MM        MM  UUUUUUUUUU  LLLLLLLLLL

                            OOOOOO    UU        UU  TTTTTTTTTT      ;;;;    5555555555
                            OOOOOO    UU        UU  TTTTTTTTTT      ;;;;    5555555555
                          OO      OO  UU        UU      TT          ;;;;    55
                          OO      OO  UU        UU      TT          ;;;;    55
                          OO      OO  UU        UU      TT                  555555
                          OO      OO  UU        UU      TT                  555555
                          OO      OO  UU        UU      TT          ;;;;          55
                          OO      OO  UU        UU      TT          ;;;;          55
                          OO      OO  UU        UU      TT          ;;;;            55
                          OO      OO  UU        UU      TT          ;;;;            55
                          OO      OO  UU        UU      TT            ;;    55      55
                          OO      OO  UU        UU      TT            ;;    55      55
                            OOOOOO    UUUUUUUUUU        TT          ;;        555555
                            OOOOOO    UUUUUUUUUU        TT          ;;        555555

File _DUA1:[LANTOS]SIMUL.OUT;5 (1432,76,0), last revised on 28-SEP-1988 10:40, is a 28 block sequential file owned by UIC
[GANDM,LANTOS].  The records are variable length with FORTRAN (FTN) carriage control.  The longest record is 116 bytes.

Job SIMUL (226) queued to SYS$PRINT on 28-SEP-1988 10:52 by user LANTOS, UIC [GANDM,LANTOS], under account GANDM at priority 100,
started on printer _TXA3: on 28-SEP-1988 11:03 from queue SYS$PRINT.

RRRRRRRRRR   OOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOO   RRRRRRRRRR
RRRRRRRRRR   OOOOOOOOOOOOOOOOOOOOOOOOO  Digital Equipment Corporation - VAX/VMS Version V4.6  OOOOOOOOOOOOOOOOOOOOOOOOO   RRRRRRRRRR
RRRRRRRRRR   OOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOO   RRRRRRRRRR
```

39

```
                                  INPUT DATA
                           TURNING CIRCLE MANOEUVRE
************************************************************************************************
                 DESCRIPTION                                   VALUE                  UNITS
LENGTH BETWEEN PERPENDICULARS                                 218.80                 METERS
LENGTH ON WATERLINE                                           218.80                 METERS
BREADTH                                                        23.12                 METERS
DRAFT AFT                                                       6.72                 METERS
DRAFT FWD                                                       3.38                 METERS
DISPLACEMENT                                                21900.00                 TONNES
BLOCK COEFFICIENT                                               0.88                 -----
MIDSHIP SECTION COEFFICIENT                                     1.00                 -----
WATERPLANE COEFFICIENT                                          0.91                 -----
RUDDER LATERAL AREA                                            25.1                  SQ. METERS
PROPELLER DIAMETER                                              5.70                 METERS
PROPELLER PITCH/DIAMETER RATIO                                  0.96                 -----
PROPELLER EXPANDED BLADE AREA RATIO                             0.50                 -----
SHAFT HORSEPOWER                                             5400.0                  KW
************************************************************************************************
                             SHIP SPEED - POWER DATA
 SPEED     WAVE       APPEND     BULB BOW    TRANSOM      CORR.     FRICTION     TOTAL     EFFECTIVE
          RESIST      RESIST      RESIST      RESIST      RESIST     RESIST      RESIST    HORSEPOWER
(KNOTS)    (KN)        (KN)        (KN)        (KN)        (KN)       (KN)        (KN)        (KW)
************************************************************************************************
 10.0   0.149E+02   0.332E+01   0.597E+00   0.000E+00   0.448E+02   0.129E+03   0.229E+03   0.118E+04
 11.0   0.309E+02   0.400E+01   0.673E+00   0.000E+00   0.542E+02   0.155E+03   0.288E+03   0.163E+04
 12.0   0.569E+02   0.473E+01   0.744E+00   0.000E+00   0.645E+02   0.182E+03   0.360E+03   0.222E+04
 13.0   0.960E+02   0.553E+01   0.811E+00   0.000E+00   0.757E+02   0.212E+03   0.449E+03   0.300E+04
 14.0   0.151E+03   0.639E+01   0.872E+00   0.000E+00   0.877E+02   0.243E+03   0.557E+03   0.402E+04
 15.0   0.224E+03   0.731E+01   0.928E+00   0.000E+00   0.101E+03   0.277E+03   0.687E+0[illegible]   0.[illegible]30E+[illegible]
 16.[illegible]   0.[illegible]E+03   0.829E+01   0.980E+00   0.000E+00   0.115E+03   0.313E+03   0.841E+03   0.692E+04
```

```
   17.0     0.431E+03   0.933E+01   0.103E+01   0.000E+00   0.129E+03   0.350E+03   0.102E+04    0.891E+04
   18.0     0.567E+03   0.104E+02   0.107E+01   0.000E+00   0.145E+03   0.390E+03   0.122E+04    0.113E+05
   19.0     0.728E+03   0.116E+02   0.111E+01   0.000E+00   0.162E+03   0.432E+03   0.146E+04    0.142E+05
   20.0     0.908E+03   0.128E+02   0.115E+01   0.000E+00   0.179E+03   0.476E+03   0.171E+04    0.176E+05
WAKE FRACTION =  0.450
THRUST DEDUCTION FRACTION =  0.160
FORM FACTOR OF THE HULL =  0.281
The friction resistance in the above table was
multiplied by (1.+CFORM) to obtain the total
resistance.
*****************************************************************************************************************
   TIME       LOCAL       LOCAL        LOCAL         GLOBAL        GLOBAL      YAW ANGLE   ROLL ANGLE   PROPELLER
             X-SPEED     Y-SPEED     SHIP SPEED    X-POSITION    Y-POSITION                              SPEED
  (SECS)     (KNOTS)     (KNOTS)      (KNOTS)       (METERS)      (METERS)     (DEGREES)    (DEGREES)     (RPM)
*****************************************************************************************************************
    0.0       12.50        0.00        12.50           0.00          0.00         0.0          0.0        120.0
   10.0       12.95       -0.40        12.96          65.59         -0.38         0.9          0.0        120.5
   20.0       12.93       -1.43        13.01         132.51         -1.37         6.1          0.0        120.9
   30.0       12.71       -2.21        12.90         199.17          0.75        14.2         -0.1        120.5
   40.0       12.39       -2.64        12.67         264.37          9.39        23.1         -0.2        120.0
   50.0       12.06       -2.85        12.39         326.67         25.81        31.9         -0.2        119.6
   60.0       11.72       -2.94        12.09         394.73         50.02        40.8         -0.2        119.2
   70.0       11.41       -2.97        11.79         437.45         81.41        49.5         -0.2        118.9
   80.0       11.12       -2.98        11.51         483.95        119.12        58.2         -0.2        118.6
   90.0       10.85       -2.97        11.25         523.58        162.12        66.8         -0.2        118.3
  100.0       10.60       -2.95        11.01         555.84        209.33        75.4         -0.2        118.1
  110.0       10.38       -2.94        10.79         580.43        259.64        83.9         -0.2        117.8
  120.0       10.17       -2.92        10.58         597.18        311.93        92.4         -0.2        117.6
  130.0        9.99       -2.90        10.40         606.06        365.11       100.9         -0.2        117.4
  140.0        9.81       -2.88        10.23         607.19        418.11.      109.3         -0.2        117.3
  150.0        9.66       -2.87        10.07         600.82        469.89       117.7         -0.2        117.1
  160.0        9.51       -2.85         9.93         587.31        519.50       126.0         -0.2        117.0
```

```
170.0   9.38   -2.84   9.80    567.12   566.03   134.4   -0.2   116.9
180.0   9.26   -2.82   9.69    540.85   608.66   142.7   -0.2   116.7
190.0   9.15   -2.81   9.58    509.15   646.68   151.0   -0.2   116.6
200.0   9.05   -2.80   9.48    472.76   679.44   159.3   -0.2   116.5
210.0   8.96   -2.79   9.39    432.49   706.43   167.6   -0.2   116.4
220.0   8.88   -2.78   9.30    389.21   727.24   175.8   -0.2   116.4
230.0   8.80   -2.77   9.23    343.80   741.58   184.1   -0.2   116.3
240.0   8.73   -2.77   9.16    297.20   749.28   192.3   -0.2   116.2
250.0   8.66   -2.76   9.09    250.32   750.31   200.5   -0.2   116.2
260.0   8.60   -2.75   9.03    204.08   744.73   208.7   -0.2   116.1
270.0   8.55   -2.75   8.98    159.38   732.75   216.9   -0.2   116.0
280.0   8.50   -2.74   8.93    117.07   714.69   225.1   -0.1   116.0
290.0   8.45   -2.74   8.88     77.94   690.95   233.2   -0.1   116.0
300.0   8.41   -2.73   8.84     42.72   662.08   241.4   -0.1   115.9
310.0   8.37   -2.73   8.80     12.07   628.68   249.6   -0.1   115.9
320.0   8.33   -2.72   8.76    -13.46   591.46   257.7   -0.1   115.8
330.0   8.30   -2.72   8.73    -33.40   551.16   265.9   -0.1   115.8
340.0   8.27   -2.72   8.70    -47.42   508.61   274.0   -0.1   115.8
350.0   8.24   -2.71   8.67    -55.28   464.66   282.1   -0.1   115.8
360.0   8.21   -2.71   8.65    -56.87   420.18   290.3   -0.1   115.8
370.0   8.19   -2.71   8.62    -52.19   376.04   298.4   -0.1   115.7
380.0   8.17   -2.70   8.60    -41.37   333.11   306.5   -0.1   115.7
390.0   8.15   -2.70   8.58    -24.66   292.23   314.6   -0.1   115.7
400.0   8.13   -2.70   8.56     -2.42   254.19   322.7   -0.1   115.7
410.0   8.11   -2.70   8.55     24.90   219.73   330.9   -0.1   115.7
420.0   8.09   -2.70   8.53     56.74   189.52   339.0   -0.1   115.6
430.0   8.08   -2.69   8.52     92.44   164.12   347.1   -0.1   115.6
440.0   8.07   -2.69   8.50    131.30   144.04   355.2   -0.1   115.6
450.0   8.05   -2.69   8.49    172.54   129.63   363.3   -0.1   115.6
[illegible]   [illegible]   [illegible]   [illegible]   [illegible]   [illegible]   [illegible]   -0.1   115.6
```

12

```
END OF TURNING CIRCLE MANOEUVRE


                        RESULTS FROM TIME SIMULATION ANALYSIS
                            TURNING CIRCLE MANOEUVRE
**********************************************************************************
               DESCRIPTION                                VALUE             UNITS
----------------------------------------------------------------------------------
STEADY TURNING SPEED                                      8.50              KNOTS
NON-DIMENSIONAL ADVANCE (ADVANCE/LPP)                     2.72              -----
NON-DIMENSIONAL TRANSFER (TRANSFER/LPP)                   1.38              -----
NON-DIMENSIONAL TACTICAL DIAMETER (TAC. DIA./LPP)         3.37              -----
NON-DIMENSIONAL STEADY TURNING DIAMETER (STDY. DIA./LPP)  2.75              -----
**********************************************************************************

                        RESULTS FROM THE EMPIRICAL ANALYSIS
                            TURNING CIRCLE MANOEUVRE
**********************************************************************************
               DESCRIPTION                                VALUE             UNITS
----------------------------------------------------------------------------------
STEADY TURNING SPEED                                      5.23              KNOTS
NON-DIMENSIONAL ADVANCE (ADVANCE/LPP)                     3.22              -----
NON-DIMENSIONAL TRANSFER (TRANSFER/LPP)                   1.74              -----
NON-DIMENSIONAL TACTICAL DIAMETER (TAC. DIA./LPP)         3.64              -----
NON-DIMENSIONAL STEADY TURNING DIAMETER (STDY. DIA./LPP)  3.04              -----
STANDARD DEVIATION OF (VST/VX1) = 0.185
STANDARD DEVIATION OF (ADV/LPP) = 0.162
STANDARD DEVIATION OF (TR/LPP) = 0.170
STANDARD DEVIATION OF (TACDIA/LPP) = 0.111
STANDARD DEVIATION OF (STDYDIA/LPP) = 0.244
MESSAGES FOR EMPIRICAL TURNING CIRCLE ANALYSIS
-----------------------------------------------
```

```
BLOCK COEFFICIENT IS OUTSIDE THE RANGE OF (.56 <= CB <= .87)
RATIO (B/LPP) IS OUTSIDE THE RANGE OF (.11 <= RATIO <= .18)
****************************************************************************************************

                                       CRASH STOP MANOEUVRE
****************************************************************************************************
                 DESCRIPTION                                        VALUE                UNITS
----------------------------------------------------------------------------------------------------
INITIAL SPEED OF SHIP                                               12.50                KNOTS
INITIAL RESISTANCE OF SHIP                                         404.6                 KN
MAXIMUM ASTERN THRUST                                              326.8                 KN
NON-DIMENSIONAL HEAD REACH (REACH/LPP)                               4.36                -----
****************************************************************************************************
```

```
VVVVVVVVVV    9999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999    VVVVVVVVVV
VVVVVVVVVV    9999999999999999999999999  Digital Equipment Corporation - VAX/VMS Version V4.6  9999999999999999999999999    VVVVVVVVVV
VVVVVVVVVV    9999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999    VVVVVVVVVV

                                        L       AAA   N   N  TTTTT   OOO   SSSS
                                        L      A   A  N   N    T    O   O  S
                                        L      A   A  NN  N    T    O   O  S
                                        L      A   A  N N N    T    O   O   SSS
                                        L      AAAAA  N  NN    T    O   O      S
                                        L      A   A  N   N    T    O   O      S
                                        LLLLL  A   A  N   N    T     OOO   SSSS

  AAA   L       GGGG   OOO   L              1   55555   SSSS  PPPP   III  RRRR        DDDD    AAA   TTTTT  ;;     1
 A   A  L      G      O   O  L             11   5      S      P   P   I   R   R       D   D  A   A    T    ;;    11
 A   A  L      G      O   O  L              1   555    S      P   P   I   R   R       D   D  A   A    T           1
 AAAAA  L      G  GGG O   O  L              1      5    SSS   PPPP    I   RRRR        D   D  A   A    T    ;;     1
 A   A  L      G    G O   O  L              1       5      S  P       I   R R         D   D  AAAAA    T    ;;     1
 A   A  L      G    G O   O  L              1   5   5      S  P       I   R  R    ..  D   D  A   A    T     ;     1
 A   A  LLLLL   GGG    OOO   LLLLL         111   555   SSSS   P      III  R   R   ..  DDDD   A   A    T    ;     111

File _DUA1:[LANTOS]ALGOL-15SPIR.DAT;1 (1102,108,0), last revised on 29-JUL-1988 13:29, is a 1 block sequential file owned by UIC
[QANDM,LANTOS].  The records are variable length with implied (CR) carriage control.  The longest record is 62 bytes.

Job ALGOB-15SPIR (221) queued to SYS$PRINT on 28-SEP-1988 10:14 by user LANTOS, UIC [QANDM,LANTOS], under account QANDM at priority
100, started on printer _TXA3: on 28-SEP-1988 10:25 from queue SYS$PRINT.

VVVVVVVVVV    9999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999    VVVVVVVVVV
VVVVVVVVVV    9999999999999999999999999  Digital Equipment Corporation - VAX/VMS Version V4.6  9999999999999999999999999    VVVVVVVVVV
VVVVVVVVVV    9999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999    VVVVVVVVVV
```

```
1000. , 1. 14E-6, 1, 14. 18, 3. 268E5
218. 8, 218. 8, 23. 12, 7. 93, 7. 93, 0. 88, 0. 996, 0. 914, 3. 564E7
0. , 0. , 0. , 0. , 5. 4, 0. , 0. , 0. , 2. , 0. , 0. , 0. , 0. , 0. , 0. 45, 0.
-110. , 6. 28, 0. 45, 25. 1, 3. 35, 1. 57, 2. 52, 3. , 0. , 11, 150. , 0. , 0, 1, 0. 005
2. 134, 6. 878, 5. 488, 1
50. 2, 1. 4
3, 4000. , 1. , -15. , 10, 5. 7, 0. 96, 0. 5, 4, 5. 4E6, 2
-108. 4, 7. 93, 6. 43, 1, 1, 3. 15, 1. , 3, 5.
```

```
GGGGGGGGGG     00000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000    GGGGGGGGGG
GGGGGGGGGG     00000000000000000000000000  Digital Equipment Corporation - VAX/VMS Version V4.6  000000000000000000000000000000    GGGGGGGGGG
GGGGGGGGGG     00000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000    GGGGGGGGGG

                                                  L        AAA   N   N  TTTTT   OOO    SSSS
                                                  L       A   A  N   N    T    O   O  S
                                                  L       A   A  NN  N    T    O   O  S
                                                  L       A   A  N N N    T    O   O   SSS
                                                  L       AAAAA  N  NN    T    O   O      S
                                                  L       A   A  N   N    T    O   O      S
                                                  LLLLL   A   A  N   N    T     OOO   SSSS

                                         SSSSSSSS      IIIIII    MM      MM   UU      UU   LL
                                         SSSSSSSS      IIIIII    MM      MM   UU      UU   LL
                                       SS                II      MMMM  MMMM   UU      UU   LL
                                       SS                II      MMMM  MMMM   UU      UU   LL
                                       SS                II      MM  MM  MM   UU      UU   LL
                                       SS                II      MM  MM  MM   UU      UU   LL
                                         SSSSSS          II      MM      MM   UU      UU   LL
                                         SSSSSS          II      MM      MM   UU      UU   LL
                                               SS        II      MM      MM   UU      UU   LL
                                               SS        II      MM      MM   UU      UU   LL
                                               SS        II      MM      MM   UU      UU   LL
                                               SS        II      MM      MM   UU      UU   LL
                                       SSSSSSSS        IIIIII    MM      MM   UUUUUUUUUU   LLLLLLLLLL
                                       SSSSSSSS        IIIIII    MM      MM   UUUUUUUUUU   LLLLLLLLLL

                                                OOOOOO     UU      UU   TTTTTTTTTT        ''''      666666
                                                OOOOOO     UU      UU   TTTTTTTTTT        ''''      666666
                                              OO      OO   UU      UU       TT            ''''    66
                                              OO      OO   UU      UU       TT            ''''    66
                                              OO      OO   UU      UU       TT                    66
                                              OO      OO   UU      UU       TT                    66
                                              OO      OO   UU      UU       TT            ''''    66666666
                                              OO      OO   UU      UU       TT            ''''    66666666
                                              OO      OO   UU      UU       TT            ''''    66      66
                                              OO      OO   UU      UU       TT            ''''    66      66
                                              OO      OO   UU      UU       TT              ''    66      66
                                              OO      OO   UU      UU       TT              ''    66      66
                                                OOOOOO     UUUUUUUUUU       TT            ''          666666
                                                OOOOOO     UUUUUUUUUU       TT            ''          666666

File  DUA1:[LANTOS]SIMUL.OUT;6 (47,263,0), last revised on 28-SEP-1988 10:41, is a 65 block sequential file owned by UIC
[QANDM,LANTOS].  The records are variable length with FORTRAN (FTN) carriage control.  The longest record is 116 bytes.

Job SIMUL (226) queued to SYS$PRINT on 28-SEP-1988 10:52 by user LANTOS, UIC [QANDM,LANTOS], under account QANDM at priority 100,
started on printer _TXA3: on 28-SEP-1988 11:01 from queue SYS$PRINT.

GGGGGGGGGG     00000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000    GGGGGGGGGG
GGGGGGGGGG     00000000000000000000000000  Digital Equipment Corporation - VAX/VMS Version V4.6  000000000000000000000000000000    GGGGGGGGGG
GGGGGGGGGG     00000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000    GGGGGGGGGG
```

```
                                     INPUT DATA
                                  SPIRAL MANOEUVRE
**************************************************************************************************
                  DESCRIPTION                                      VALUE              UNITS
--------------------------------------------------------------------------------------------------
LENGTH BETWEEN PERPENDICULARS                                     218.80             METERS
LENGTH ON WATERLINE                                               218.80             METERS
BREADTH                                                            23.12             METERS
DRAFT AFT                                                           7.93             METERS
DRAFT FWD                                                           7.93             METERS
DISPLACEMENT                                                    35640.00             TONNES
BLOCK COEFFICIENT                                                   0.88             -----
MIDSHIP SECTION COEFFICIENT                                         1.00             -----
WATERPLANE COEFFICIENT                                              0.91             -----
RUDDER LATERAL AREA                                                25.1              SQ. METERS
PROPELLER DIAMETER                                                  5.70             METERS
PROPELLER PITCH/DIAMETER RATIO                                      0.96             -----
PROPELLER EXPANDED BLADE AREA RATIO                                 0.50             -----
SHAFT HORSEPOWER                                                 5400.0              KW
**************************************************************************************************
                              SHIP SPEED - POWER DATA
 SPEED     WAVE       APPEND     BULB BOW    TRANSOM      CORR.     FRICTION     TOTAL      EFFECTIVE
          RESIST      RESIST      RESIST      RESIST     RESIST      RESIST     RESIST     HORSEPOWER
(KNOTS)    (KN)        (KN)        (KN)        (KN)        (KN)        (KN)       (KN)        (KW)
**************************************************************************************************
 10.0   0.528E+01   0.332E+01   0.105E+02   0.000E+00   0.364E+02   0.153E+03   0.253E+03   0.130E+04
 11.0   0.128E+02   0.400E+01   0.121E+02   0.000E+00   0.440E+02   0.183E+03   0.310E+03   0.175E+04
 12.0   0.269E+02   0.473E+01   0.136E+02   0.000E+00   0.524E+02   0.216E+03   0.376E+03   0.232E+04
 13.0   0.507E+02   0.553E+01   0.151E+02   0.000E+00   0.615E+02   0.251E+03   0.457E+03   0.305E+04
 14.0   0.877E+02   0.639E+01   0.165E+02   0.000E+00   0.713E+02   0.288E+03   0.554E+03   0.399E+04
 15.0   0.142E+03   0.731E+01   0.178E+02   0.000E+00   0.819E+02   0.328E+03   0.672E+03   0.519E+04
 16[illegible] 0[illegible]E+03 [illegible].82[illegible]01 [illegible]70E+[illegible] 0.[illegible]00 0.931E+02 0.370E+03 0.815E+03 0.671E+04
 17.0   0.314E+03  0.933E+01  0.202E+02  0.000E+00  0.105E+03  0.415E+03  0.985E+03  0.861E+04
 18.0   0.438E+03  0.104E+02  0.213E+02  0.000E+00  0.118E+03  0.462E+03  0.118E+04  0.110E+05
 19.0   0.594E+03  0.116E+02  0.223E+02  0.000E+00  0.131E+03  0.511E+03  0.142E+04  0.139E+05
 20.0   0.777E+03  0.128E+02  0.232E+02  0.000E+00  0.146E+03  0.563E+03  0.169E+04  0.173E+05
WAKE FRACTION =  0.450
THRUST DEDUCTION FRACTION =  0.170
FORM FACTOR OF THE HULL =  0.292
The friction resistance in the above table was
multiplied by (1.+CFORM) to obtain the total
resistance.
******************************************************************************************************
  TIME     LOCAL      LOCAL       LOCAL        GLOBAL       GLOBAL      YAW ANGLE   ROLL ANGLE   PROPELLER
          X-SPEED    Y-SPEED   SHIP SPEED   X-POSITION   Y-POSITION                               SPEED
 (SECS)   (KNOTS)    (KNOTS)     (KNOTS)     (METERS)     (METERS)     (DEGREES)    (DEGREES)      (RPM)
******************************************************************************************************
    0.0    10.50       0.00       10.50          0.00         0.00         0.0          0.0        120.0
   10.0    10.84       0.23       10.84         54.90         0.29        -0.7          0.0        120.3
   20.0    11.15       0.57       11.16        111.49         0.63        -2.9          0.0        120.7
   30.0    11.42       0.92       11.45        169.67        -0.14        -6.3          0.1        121.0
   40.0    11.64       1.25       11.71        229.18        -3.23       -10.6          0.1        121.2
   50.0    11.81       1.53       11.91        289.59        -9.79       -15.5          0.2        121.4
   60.0    11.94       1.76       12.07        350.31       -20.77       -20.9          0.2        121.5
   70.0    12.04       1.93       12.19        410.60       -36.89       -26.6          0.2        121.6
   80.0    12.11       2.06       12.28        469.68       -58.61       -32.6          0.3        121.6
   90.0    12.15       2.16       12.34        526.68       -86.16       -38.8          0.3        121.7
  100.0    12.18       2.22       12.38        580.78      -119.52       -45.0          0.3        121.7
  110.0    12.20       2.27       12.41        631.19      -158.53       -51.4          0.3        121.7
  120.0    12.21       2.31       12.42        677.16      -202.83       -57.8          0.3        121.8
  130.0    12.21       2.33       12.43        718.03      -251.96       -64.2          0.3        121.8
  140.0    12.21       2.35       12.44        753.20      -305.35       -70.7          0.3        121.8
  150.0    12.21       2.36       12.44        782.19      -362.35       -77.2          0.3        121.8
  160.0    12.21       2.37       12.44        804.58      -422.24       -83.7          0.3        121.8
```

```
   170.0     12.20      2.37      12.43      820.07     -484.26     -90.2      0.3      121.8
   180.0     12.20      2.37      12.43      828.45     -547.62     -96.7      0.3      121.7
   190.0     12.19      2.38      12.42      829.60     -611.50    -103.3      0.3      121.7
 RUDDER ANGLE =   -10.00000

   200.0     12.21      2.34      12.43      823.46     -675.08    -109.7      0.4      121.7
   210.0     12.25      2.27      12.46      810.07     -737.64    -115.8      0.3      121.8
   220.0     12.31      2.22      12.51      789.81     -798.57    -121.7      0.3      121.9
   230.0     12.38      2.19      12.57      763.06     -857.25    -127.5      0.3      121.9
   240.0     12.45      2.16      12.64      730.17     -913.09    -133.3      0.3      122.0
   250.0     12.52      2.15      12.70      691.49     -965.52    -139.1      0.3      122.1
   260.0     12.59      2.14      12.77      647.43    -1013.98    -144.8      0.3      122.1
   270.0     12.66      2.14      12.84      598.42    -1057.94    -150.6      0.3      122.2
   280.0     12.72      2.14      12.90      544.93    -1096.91    -156.4      0.3      122.3
   290.0     12.79      2.14      12.96      487.49    -1130.43    -162.1      0.3      122.4
   300.0     12.85      2.14      13.03      426.67    -1158.10    -167.9      0.3      122.4
   310.0     12.91      2.14      13.08      363.06    -1179.57    -173.7      0.3      122.5
 RUDDER ANGLE =   -5.000000

   320.0     12.96      2.14      13.14      297.33    -1194.55    -179.5      0.3      122.5
   330.0     13.05      2.06      13.21      230.08    -1202.71    -185.0      0.3      122.6
   340.0     13.15      2.00      13.30      161.93    -1204.17    -190.2      0.3      122.8
   350.0     13.26      1.94      13.40       93.45    -1199.14    -195.2      0.3      122.9
   360.0     13.38      1.91      13.51       25.17    -1187.78    -200.1      0.3      123.0
   370.0     13.49      1.88      13.62      -42.36    -1170.22    -205.0      0.3      123.[illegible]
   380.0     13.61      1.86      13.74     -108.63    -1146.61    -209.9      0.3      123.2
   390.0     13.72      1.85      13.85     -173.11    -1117.09    -214.8      0.3      123.4
   400.0     13.83      1.85      13.95     -235.30    -1081.84    -219.6      0.3      123.5
   410.0     13.94      1.84      14.06     -294.70    -1041.09    -224.4      0.3      123.6
   420.0     14.04      1.84      14.16     -3[illegible].81     -995.07    -229.[illegible]      0.[illegible]      123.7
   43[illegible]     [illegible]4      1.[illegible]      [illegible].26     [illegible]403.15     -[illegible].06    -234.2      0.3      123.8
   440.0     14.23      1.85      14.35      -451.27     -888.39    -239.0     0.3     123.9
 RUDDER ANGLE =   0.0000000E+00

   450.0     14.33      1.83      14.44      -494.71     -828.42    -243.9     0.4     124.0
   460.0     14.44      1.74      14.55      -533.03     -764.48    -248.3     0.3     124.2
   470.0     14.57      1.65      14.66      -566.27     -697.14    -252.4     0.3     124.3
   480.0     14.71      1.57      14.79      -594.55     -626.87    -256.3     0.3     124.5
   490.0     14.85      1.51      14.93      -617.92     -554.11    -260.0     0.3     124.6
   500.0     14.99      1.46      15.06      -636.41     -479.23    -263.6     0.3     124.8
   510.0     15.14      1.42      15.20      -650.03     -402.59    -267.1     0.3     125.0
   520.0     15.28      1.39      15.34      -658.80     -324.51    -270.6     0.2     125.1
   530.0     15.42      1.37      15.48      -662.72     -245.32    -274.0     0.2     125.3
   540.0     15.56      1.34      15.62      -661.80     -165.33.   -277.3     0.2     125.4
   550.0     15.70      1.33      15.76      -656.04      -84.84    -280.6     0.2     125.6
   560.0     15.83      1.31      15.89      -645.46       -4.15    -283.9     0.2     125.8
   570.0     15.96      1.30      16.01      -630.07       76.44    -287.1     0.2     125.9
   580.0     16.09      1.30      16.14      -609.90      156.64    -290.4     0.2     126.1
   590.0     16.21      1.29      16.26      -584.99      236.15    -293.6     0.2     126.2
   600.0     16.32      1.29      16.37      -555.38      314.69    -296.8     0.2     126.3
 RUDDER ANGLE =    5.000000

   610.0     16.44      1.20      16.48      -521.08      391.91    -299.8     0.2     126.5
   620.0     16.56      1.05      16.60      -482.30      467.63    -302.2     0.2     126.6
   630.0     16.70      0.90      16.73      -439.70      541.99    -304.1     0.2     126.8
   640.0     16.85      0.75      16.86      -393.85      615.20    -305.6     0.2     127.0
   650.0     16.99      0.59      17.00      -345.25      687.49    -306.7     0.1     127.1
   660.0     17.14      0.43      17.15      -294.42      759.14    -307.4     0.1     127.3
   670.0     17.29      0.25      17.29      -241.85      830.45    -307.6     0.1     127.5
   680.0     17.44      0.06      17.44      -188.06      901.78    -307.4     0.0     127.7
   690.0     17.57     -0.16      17.58      -133.61      973.52    -306.6     0.0     127.8
   700.0     17.70     -0.40      17.70       -79.16     1046.12    -305.2     0.0     128.0
   710.0     17.81     -0.65     17.82      -25.48     1120.06    -303.3     -0.1     128.1
   720.0     17.89     -0.89     17.91       26.55     1195.83    -300.7     -0.1     128.2
   730.0     17.95     -1.12     17.98       75.97     1273.82    -297.5     -0.2     128.3
   740.0     17.98     -1.34     18.03      121.76     1354.33    -293.8     -0.2     128.3
   750.0     17.98     -1.52     18.04      162.91     1437.47    -289.7     -0.3     128.3
   760.0     17.95     -1.68     18.03      198.45     1523.17    -285.1     -0.3     128.3
   770.0     17.90     -1.81     18.00      227.49     1611.16    -280.2     -0.4     128.3
   780.0     17.84     -1.92     17.94      249.29     1700.97    -275.1     -0.4     128.2
   790.0     17.76     -2.00     17.87      263.28     1792.00    -269.8     -0.4     128.1
   800.0     17.67     -2.06     17.79      269.03     1883.53    -264.3     -0.4     128.0
   810.0     17.58     -2.10     17.71      266.28     1974.76    -258.8     -0.4     127.9
   820.0     17.48     -2.13     17.61      254.95     2064.87    -253.1     -0.4     127.8
   830.0     17.39     -2.15     17.52      235.07     2152.99    -247.4     -0.4     127.6
   840.0     17.29     -2.17     17.43      206.84     2238.29    -241.7     -0.4     127.5
   850.0     17.20     -2.17     17.34      170.54     2319.97    -236.0     -0.4     127.4
   860.0     17.11     -2.18     17.25      126.58     2397.25    -230.3     -0.4     127.3
   870.0     17.02     -2.18     17.16       75.43     2469.43    -224.5     -0.4     127.2
   880.0     16.94     -2.17     17.08       17.66     2535.86    -218.8     -0.4     127.1
   890.0     16.86     -2.17     17.00      -46.11     2595.95    -213.1     -0.4     127.0
RUDDER ANGLE =    10.00000

   900.0     16.78     -2.21     16.92     -115.18     2649.22    -207.4     -0.4     126.9
   910.0     16.65     -2.32     16.81     -188.76     2695.16    -201.1     -0.4     126.8
   920.0     16.51     -2.40     16.68     -266.18     2732.85    -194.6     -0.4     126.6
   930.0     16.35     -2.45     16.54     -346.60     2761.58    -187.9     -0.5     126.4
   940.0     16.20     -2.49     16.39     -429.01     2780.86    -181.1     -0.5     126.2
   950.0     16.04     -2.51     16.24     -512.33     2790.46    -174.4     -0.5     126.0
   960.0     15.89     -2.52     16.09     -595.44     2790.33    -167.6     -0.5     125.9
   970.0     15.75     -2.52     15.95     -677.23     2780.60    -160.8     -0.5     125.7
   980.0     [illegible]     -2.[illegible]     [illegible]81     [illegible].63     2[illegible]56     -15[illegible]     -0.[illegible]     125.5
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    990.0    15.48     -2.50     15.68     -832.62     2733.63    -147.3     -0.5     125.4
   1000.0    15.36     -2.49     15.56     -904.27     2697.34    -140.6     -0.4     125.2
   1010.0    15.25     -2.48     15.45     -970.72     2653.31    -133.9     -0.4     125.1
   1020.0    15.14     -2.47     15.34    -1031.20     2602.26    -127.2     -0.4     125.0
 RUDDER ANGLE =    15.00000

   1030.0    15.00     -2.54     15.21    -1085.05     2545.07    -120.4     -0.4     124.8
   1040.0    14.83     -2.61     15.06    -1131.47     2482.62    -113.2     -0.5     124.6
   1050.0    14.65     -2.65     14.89    -1169.59     2415.74    -105.9     -0.5     124.4
   1060.0    14.48     -2.67     14.72    -1198.82     2345.45     -98.5     -0.5     124.2
   1070.0    14.31     -2.68     14.56    -1218.81     2272.88     -91.2     -0.4     124.1
   1080.0    14.15     -2.68     14.40    -1229.40     2199.22     -83.8     -0.4     123.9
   1090.0    13.99     -2.67     14.24    -1230.62     2125.61     -76.5     -0.4     123.7
   1100.0    13.84     -2.66     14.10    -1222.67     2053.20     -69.2     -0.4     123.5
   1110.0    13.71     -2.65     13.96    -1205.88     1983.06     -62.0     -0.4     123.4
   1120.0    13.58     -2.64     13.83    -1180.70     1916.20     -54.8     -0.4     123.2
   1130.0    13.46     -2.62     13.71    -1147.70     1853.56     -47.6     -0.4     123.1
   1140.0    13.35     -2.61     13.60    -1107.55     1795.98     -40.5     -0.4     123.0
 RUDDER ANGLE =    10.00000

   1150.0    13.27     -2.54     13.51    -1060.91     1744.24     -33.6     -0.4     122.9
   1160.0    13.24     -2.45     13.47    -1008.51     1698.82     -27.0     -0.4     122.9
   1170.0    13.23     -2.39     13.44     -951.31     1659.95     -20.7     -0.4     122.8
   1180.0    13.23     -2.34     13.43     -890.13     1627.86     -14.4     -0.4     122.8
   1190.0    13.23     -2.31     13.43     -825.80     1602.76      -8.2     -0.4     122.8
   1200.0    13.24     -2.29     13.44     -759.08     1584.86      -2.1     -0.4     122.9
   1210.0    13.25     -2.28     13.45     -690.78     1574.27       4.0     -0.4     122.9
   1220.0    13.27     -2.27     13.46     -621.68     1571.09      10.1     -0.4     122.9
   1230.0    13.28     -2.26     13.47     -552.56     1575.34      16.2     -0.4     122.9
   1240.0    13.30     -2.26     13.49     -484.22     1586.94      22.3     -0.4     122.9
   1250.0    13.31     -2.26     13.50     -417.43     1605.78      28.4     -0.4     122.9
   1260. 0     13. 33     -2. 25      13. 52      -352. 95     1631. 64     34. 5      -0. 4      123. 0
   1270. 0     13. 34     -2. 25      13. 53      -291. 52     1664. 24     40. 6      -0. 4      123. 0
 RUDDER ANGLE =    5. 000000

   1280. 0     13. 38     -2. 18      13. 56      -233. 87     1703. 31     46. 5      -0. 3      123. 0
   1290. 0     13. 45     -2. 10      13. 62      -180. 49     1748. 38     51. 9      -0. 3      123. 1
   1300. 0     13. 53     -2. 03      13. 69      -131. 63     1798. 78     57. 2      -0. 3      123. 2
   1310. 0     13. 62     -1. 99      13. 77       -87. 57     1853. 93     62. 4      -0. 3      123. 3
   1320. 0     13. 72     -1. 95      13. 86       -48. 59     1913. 31     67. 5      -0. 3      123. 4
   1330. 0     13. 81     -1. 93      13. 95       -14. 98     1976. 40     72. 5      -0. 3      123. 5
   1340. 0     13. 90     -1. 91      14. 04        13. 01     2042. 68     77. 5      -0. 3      123. 6
   1350. 0     14. 00     -1. 91      14. 13        35. 12     2111. 64     82. 5      -0. 3      123. 7
   1360. 0     14. 09     -1. 90      14. 21        51. 15     2182. 72     87. 5      -0. 3      123. 8
   1370. 0     14. 17     -1. 90      14. 30        60. 91     2255. 39     92. 5      -0. 3      123. 9
   1380. 0     14. 26     -1. 90      14. 38        64. 27     2329. 07     97. 5      -0. 3      124. 0
   1390. 0     14. 34     -1. 90      14. 46        61. 13     2403. 18    102. 5      -0. 3      124. 1
   1400. 0     14. 41     -1. 90      14. 54        51. 43     2477. 13    107. 5      -0. 3      124. 1
 RUDDER ANGLE =   0. 0000000E+00

   1410. 0     14. 50     -1. 83      14. 62        35. 09     2550. 29    112. 3      -0. 3      124. 2
   1420. 0     14. 61     -1. 73      14. 72        12. 33     2622. 20    116. 7      -0. 3      124. 4
   1430. 0     14. 74     -1. 64      14. 83       -16. 32     2692. 56    120. 7      -0. 3      124. 5
   1440. 0     14. 87     -1. 57      14. 95       -50. 46     2761. 12    124. 6      -0. 3      124. 7
   1450. 0     15. 01     -1. 51      15. 08       -89. 74     2827. 63    128. 3      -0. 3      124. 8
   1460. 0     15. 15     -1. 46      15. 22      -133. 86     2891. 86    131. 9      -0. 3      125. 0
   1470. 0     15. 28     -1. 43      15. 35      -182. 55     2953. 58    135. 4      -0. 3      125. 1
   1480. 0     15. 42     -1. 39      15. 49      -235. 55     3012. 57    138. 9      -0. 2      125. 3
   1490. 0     15. 56     -1. 37      15. 62      -292. 62     3068. 62    142. 3      -0. 2      125. 4
   1500. 0     15. 69     -1. 35      15. 75      -353. 52     3121. 52    145. 7      -0. 2      125. 6
   1510. 0     15. 82     -1. 33      15. 88      -418. 02     3171. 09    149. 0      -0. 2      125. 7
   [illegible]520[illegible]   [illegible]   [illegible]. 3[illegible]   [illegible]0   [illegible]88   3[illegible]2   15[illegible]   -0. [illegible]   [illegible]. 9
   1530.0   16.07   -1.31   16.13    -556.86   3259.43   155.5   -0.2   126.0
   1540.0   16.19   -1.30   16.25    -630.73   3297.84   158.8   -0.2   126.2
   1550.0   16.31   -1.30   16.36    -707.23   3332.19   162.0   -0.2   126.3
   1560.0   16.42   -1.29   16.47    -786.12   3362.31   165.2   -0.2   126.4
 RUDDER ANGLE =   -5.000000

   1570.0   16.53   -1.19   16.57    -867.13   3387.98   168.2   -0.2   126.6
   1580.0   16.65   -1.06   16.69    -949.96   3409.35   170.6   -0.2   126.7
   1590.0   16.79   -0.92   16.81   -1034.30   3426.95   172.5   -0.2   126.9
   1600.0   16.93   -0.78   16.94   -1119.93   3441.28   174.2   -0.2   127.1
   1610.0   17.07   -0.64   17.08   -1206.68   3452.81   175.4   -0.1   127.2
   1620.0   17.21   -0.50   17.22   -1294.42   3462.03   176.3   -0.1   127.4
   1630.0   17.36   -0.35   17.36   -1383.06   3469.45   176.8   -0.1   127.6
   1640.0   17.50   -0.18   17.50   -1472.51   3475.62   176.9   -0.1   127.7
   1650.0   17.64    0.01   17.64   -1562.72   3481.11   176.6    0.0   127.9
   1660.0   17.76    0.22   17.76   -1653.61   3486.61   175.7    0.0   128.1
   1670.0   17.88    0.44   17.88   -1745.10   3492.87   174.3    0.0   128.2
   1680.0   17.98    0.67   17.99   -1837.04   3500.76   172.3    0.1   128.3
   1690.0   18.05    0.90   18.08   -1929.23   3511.21   169.7    0.1   128.4
   1700.0   18.10    1.12   18.14   -2021.34   3525.16   166.6    0.2   128.5
   1710.0   18.13    1.33   18.18   -2112.93   3543.52   162.9    0.2   128.5
   1720.0   18.13    1.51   18.19   -2203.45   3567.11   158.8    0.3   128.5
   1730.0   18.10    1.66   18.18   -2292.21   3596.58   154.4    0.3   128.5
   1740.0   18.05    1.79   18.14   -2378.47   3632.39   149.6    0.4   128.4
   1750.0   17.99    1.89   18.09   -2461.42   3674.81   144.5    0.4   128.4
   1760.0   17.91    1.97   18.02   -2540.22   3723.89   139.3    0.4   128.3
   1770.0   17.82    2.03   17.94   -2614.08   3779.50   133.9    0.4   128.2
   1780.0   17.73    2.08   17.85   -2682.23   3841.32   128.4    0.4   128.0
   1790.0   17.63    2.11   17.76   -2743.98   3908.91   122.9    0.4   127.9
   1800.0   17.53    2.13   17.66   -2798.72   3981.69   117.3    0.4   127.8
   1810.0   17.44    2.14   17.57   -2845.94   4059.00   111.6    0.4   127.7
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   1820.0     17.34     2.15     17.48     -2885.20     4140.10     105.9     0.4     127.6
   1830.0     17.25     2.16     17.39     -2916.18     4224.21     100.3     0.4     127.5
   1840.0     17.16     2.16     17.30     -2938.65     4310.52      94.6     0.4     127.4
   1850.0     17.08     2.16     17.22     -2952.47     4398.18      88.9     0.4     127.3
   1860.0     17.00     2.15     17.14     -2957.59     4486.35      83.3     0.4     127.2
 RUDDER ANGLE =   -10.00000

   1870.0     16.92     2.17     17.06     -2954.06     4574.21      77.6     0.4     127.1
   1880.0     16.80     2.27     16.96     -2942.08     4660.86      71.6     0.4     126.9
   1890.0     16.67     2.35     16.83     -2921.44     4745.25      65.2     0.4     126.8
   1900.0     16.52     2.41     16.70     -2892.09     4826.31      58.6     0.5     126.6
   1910.0     16.37     2.45     16.56     -2854.27     4902.98      52.0     0.5     126.4
   1920.0     16.22     2.47     16.41     -2808.46     4974.28      45.4     0.5     126.3
   1930.0     16.08     2.48     16.27     -2755.28     5039.33      38.7     0.5     126.1
   1940.0     15.94     2.48     16.13     -2695.52     5097.35      32.0     0.5     125.9
   1950.0     15.81     2.48     16.00     -2630.04     5147.70      25.3     0.5     125.8
   1960.0     15.68     2.47     15.87     -2559.78     5189.86      18.7     0.5     125.6
   1970.0     15.56     2.46     15.75     -2485.73     5223.42      12.1     0.5     125.5
   1980.0     15.45     2.45     15.64     -2408.89     5248.11       5.5     0.4     125.3
   1990.0     15.34     2.44     15.54     -2330.29     5263.78      -1.0     0.4     125.2
 RUDDER ANGLE =   -15.00000

   2000.0     15.22     2.49     15.42     -2250.97     5270.42      -7.7     0.4     125.1
   2010.0     15.06     2.55     15.28     -2172.08     5268.06     -14.7     0.4     124.9
   2020.0     14.90     2.60     15.12     -2094.79     5256.51     -21.9     0.5     124.7
   2030.0     14.73     2.63     14.96     -2020.25     5235.92     -29.1     0.5     124.5
   2040.0     14.57     2.64     14.80     -1949.55     5206.66     -36.3     0.5     124.3
   2050.0     14.41     2.64     14.65     -1883.70     5169.29     -43.5     0.4     124.2
   2060.0     14.26     2.63     14.50     -1823.59     5124.53     -50.7     0.4     124.0
   2070.0     14.12     2.62     14.36     -1770.01     5073.20  [illegible] [illegible] [illegible]
   20[illegible] [illegible].99     2.61     14.23     -1723.61     5016.20     -65.0     0.4     123.7
 2090.0     13.86      2.60       14.11       -1684.92      4954.49      -72.1        0.4        123.6
 2100.0     13.75      2.59       13.99       -1654.33      4889.06      -79.1        0.4        123.4
 2110.0     13.64      2.58       13.88       -1632.13      4820.95      -86.1        0.4        123.3
RUDDER ANGLE =  -20.00000

END OF SPIRAL TEST


                            RESULTS FROM TIME SIMULATION ANALYSIS
                                     SPIRAL MANOEUVRE
****************************************************************************************************
                  DESCRIPTION                                  VALUE                    UNITS
----------------------------------------------------------------------------------------------------
 THE RESULTS FOR THE SPIRAL TEST ARE SUMMARIZED BELOW.  THEY ARE THE
 CONSTANT RATES OF TURN AT EACH RUDDER ANGLE, STARTING WITH THE INITIAL
 ANGLE, AND SUBSEQUENTLY CHANGING BY "DELTANG".
 THE INITIAL RUDDER ANGLE IS
                                                              -15.00                    DEGREES
 THE CHANGE OF RUDDER ANGLE IS                                 5.00                     DEGREES
  THE ANGLE IS = -15.0
THE CONSTANT YAW RATE IS                                   -0.652E+00                  DEG./SEC.
  THE ANGLE IS = -10.0
THE CONSTANT YAW RATE IS                                   -0.580E+00                  DEG./SEC.
  THE ANGLE IS =  -5.0
THE CONSTANT YAW RATE IS                                   -0.489E+00                  DEG./SEC.
  THE ANGLE IS =   0.0
THE CONSTANT YAW RATE IS                                   -0.321E+00                  DEG./SEC.
  THE ANGLE IS =   5.0
THE CONSTANT YAW RATE IS                                    0.570E+00                  DEG./SEC.
  THE ANGLE IS =  10.0
THE CONSTANT YAW RATE IS                                    0.663E+00                  DEG./SEC.
  THE ANGLE IS =  15.0
THE CONSTANT YAW RATE IS                                    0.711E+00                  DEG./SEC.
  THE ANGLE IS =  10.0
THE CONSTANT YAW RATE IS                                    0.609E+00                  DEG./SEC.
  THE ANGLE IS =   5.0
THE CONSTANT YAW RATE IS                                    0.503E+00                  DEG./SEC.
```

```
  THE ANGLE IS =   0.0
THE CONSTANT YAW RATE IS
  THE ANGLE IS =  -5.0                                           0.323E+00                  DEG. /SEC.
THE CONSTANT YAW RATE IS
  THE ANGLE IS = -10.0                                          -0.564E+00                  DEG. /SEC.
THE CONSTANT YAW RATE IS
  THE ANGLE IS = -15.0                                          -0.653E+00                  DEG. /SEC.
THE CONSTANT YAW RATE IS
                                                                -0.699E+00                  DEG. /SEC.
**************************************************************************************************

                          RESULTS FROM THE EMPIRICAL ANALYSIS

                                     CRASH STOP MANOEUVRE
**************************************************************************************************
                 DESCRIPTION                                      VALUE                     UNITS
INITIAL SPEED OF SHIP
INITIAL RESISTANCE OF SHIP                                        12.50                     KNOTS
MAXIMUM ASTERN THRUST                                            416.5                       KN
NON-DIMENSIONAL HEAD REACH (REACH/LPP)                           326.8                       KN
                                                                   6.79                     -----
**************************************************************************************************
```

```
WWWWWWWWWW   99999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999   WWWWWWWWWW
WWWWWWWWWW   999999999999999999999999  Digital Equipment Corporation - VAX/VMS Version V4.6  999999999999999999999999   WWWWWWWWWW
WWWWWWWWWW   99999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999   WWWWWWWWWW

                                   L      AAA   N   N  TTTTT   OOO   SSSS
                                   L     A   A  N   N    T    O   O S
                                   L     A   A  NN  N    T    O   O S
                                   L     A   A  N N N    T    O   O  SSS
                                   L     AAAAA  N  NN    T    O   O     S
                                   L     A   A  N   N    T    O   O     S
                                   LLLLL A   A  N   N    T     OOO  SSSS

  AAAAAA    LL            00000000    000000    LL                      333333    5555555555    CCCCCCCC  IIIIII  RRRRRRRR
  AAAAAA    LL            00000000    000000    LL                      333333    5555555555    CCCCCCCC  IIIIII  RRRRRRRR
AA      AA  LL          00          00      00  LL                    33      33  55          CC            II    RR      RR
AA      AA  LL          00          00      00  LL                    33      33  55          CC            II    RR      RR
AA      AA  LL          00          00      00  LL                            33  555555      CC            II    RR      RR
AA      AA  LL          00          00      00  LL                            33  555555      CC            II    RR      RR
AA      AA  LL          00          00      00  LL                          33          55    CC            II    RRRRRRRR
AA      AA  LL          00          00      00  LL                          33          55    CC            II    RRRRRRRR
AAAAAAAAAA  LL          00    000000  00      00  LL                            33          55  CC            II    RR  RR
AAAAAAAAAA  LL          00    000000  00      00  LL                            33          55  CC            II    RR  RR
AA      AA  LL          00        00  00      00  LL                    33      33  55      55  CC            II    RR    RR
AA      AA  LL          00        00  00      00  LL                    33      33  55      55  CC            II    RR    RR
AA      AA  LLLLLLLLLL    000000      000000    LLLLLLLLLL                333333      555555      CCCCCCCC  IIIIII  RR      RR
AA      AA  LLLLLLLLLL    000000      000000    LLLLLLLLLL                333333      555555      CCCCCCCC  IIIIII  RR      RR

                                DDDDDDDD      AAAAAA    TTTTTTTTTT    ;;;;        11
                                DDDDDDDD      AAAAAA    TTTTTTTTTT    ;;;;        11
                                DD      DD  AA      AA      TT        ;;;;      1111
                                DD      DD  AA      AA      TT        ;;;;      1111
                                DD      DD  AA      AA      TT                    11
                                DD      DD  AA      AA      TT                    11
                                DD      DD  AA      AA      TT        ;;;;        11
                                DD      DD  AAAAAAAAAA      TT        ;;;;        11
                                DD      DD  AAAAAAAAAA      TT        ;;;;        11
                        ....    DD      DD  AA      AA      TT          ;;        11
                        ....    DD      DD  AA      AA      TT          ;;        11
                        ....    DD      DD  AA      AA      TT          ;;        11
                        ....    DDDDDDDD    AA      AA      TT        ;;        111111
                        ....    DDDDDDDD    AA      AA      TT        ;;        111111

File _DUA1:[LANTOS]ALGOL-35CIR.DAT;1 (998,111,0), last revised on 29-JUL-1988 13:23, is a 1 block sequential file owned by UIC
[QANDM,LANTOS].  The records are variable length with implied (CR) carriage control.  The longest record is 62 bytes.

Job ALGOB-15SPIR (221) queued to SYS$PRINT on 28-SEP-1988 10:14 by user LANTOS, UIC [QANDM,LANTOS], under account QANDM at priority
100, started on printer _TXA3: on 28-SEP-1988 10:25 from queue SYS$PRINT.
WWWWWWWWWW   99999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999   WWWWWWWWWW
WWWWWWWWWW   999999999999999999999999  Digital Equipment Corporation - VAX/VMS Version V4.6  999999999999999999999999   WWWWWWWWWW
WWWWWWWWWW   99999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999   WWWWWWWWWW
```

```
1000.,1.14E-6,1,14.18,3.268E5
218.8,218.8,23.12,7.93,7.93,0.88,0.996,0.914,3.564E7
0.,0.,0.,0.,5.4,0.,0.,0.,2.,0.,0.,0.,0.,0.,0.45,0.
-110.,6.28,0.45,25.1,3.35,1.57,2.52,3.,0.,11,150.,0.,0,1,0.005
2.134,6.878,5.488,1
50.2,1.4
1,4000.,1.,-35.,10,5.7,0.96,0.5,4,5.4E6,2
-108.4,7.93,6.43,1,1,3.15,1.,3,5.
```

```
PPPPPPPPPP   000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
PPPPPPPPPP   0000000000000000000000000  Digital Equipment Corporation - VAX/VMS Version V4.6  0000000000000000000000000   PPPPPPPPPP
PPPPPPPPPP   000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000   PPPPPPPPPP
                                                                                                                       PPPPPPPPPP

                              L       AAA    N   N  TTTTT   000    SSSS
                              L      A   A   N   N    T    O   O  S
                              L      A   A   NN  N    T    O   O  S
                              L      A   A   N N N    T    O   O   SSS
                              L      AAAAA   N  NN    T    O   O      S
                              L      A   A   N   N    T    O   O      S
                              LLLLL  A   A   N   N    T     000   SSSS

                           SSSSSSSS    IIIIII    MM        MM  UU        UU  LL
                           SSSSSSSS    IIIIII    MM        MM  UU        UU  LL
                         SS              II      MMMM    MMMM  UU        UU  LL
                         SS              II      MMMM    MMMM  UU        UU  LL
                         SS              II      MM  MM  MM    UU        UU  LL
                         SS              II      MM  MM  MM    UU        UU  LL
                           SSSSSS        II      MM        MM  UU        UU  LL
                           SSSSSS        II      MM        MM  UU        UU  LL
                                 SS      II      MM        MM  UU        UU  LL
                                 SS      II      MM        MM  UU        UU  LL
                                 SS      II      MM        MM  UU        UU  LL
                                 SS      II      MM        MM  UU        UU  LL
                         SSSSSSSS      IIIIII    MM        MM  UUUUUUUUUU  LLLLLLLLLL
                         SSSSSSSS      IIIIII    MM        MM  UUUUUUUUUU  LLLLLLLLLL

                               000000    UU        UU  TTTTTTTTTT        ;;;;    77777777
                               000000    UU        UU  TTTTTTTTTT        ;;;;    77777777
                             00      00  UU        UU      TT            ;;;;          77
                             00      00  UU        UU      TT            ;;;;          77
                             00      00  UU        UU      TT                          77
                             00      00  UU        UU      TT                          77
                             00      00  UU        UU      TT            ;;;;        77
                             00      00  UU        UU      TT            ;;;;        77
                             00      00  UU        UU      TT            ;;;;      77
                             00      00  UU        UU      TT            ;;;;      77
                    ....     00      00  UU        UU      TT              ;;    77
                    ....     00      00  UU        UU      TT              ;;    77
                    ....       000000    UUUUUUUUUU        TT            ;;    77
                    ....       000000    UUUUUUUUUU        TT            ;;    77

File  DUA1:[LANTOS]SIMUL.OUT;7 (54,197,0), last revised on 28-SEP-1988 10:42, is a 29 block sequential file owned by UIC
[QANDM,LANTOS].  The records are variable length with FORTRAN (FTN) carriage control.  The longest record is 116 bytes.

Job SIMUL (226) queued to SYS$PRINT on 28-SEP-1988 10:52 by user LANTOS, UIC [QANDM,LANTOS], under account QANDM at priority 100,
started on printer _TXA3: on 28-SEP-1988 11:00 from queue SYS$PRINT.

PPPPPPPPPP   000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
PPPPPPPPPP   0000000000000000000000000  Digital Equipment Corporation - VAX/VMS Version V4.6  0000000000000000000000000   PPPPPPPPPP
PPPPPPPPPP   000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000   PPPPPPPPPP
                                                                                                                       PPPPPPPPPP
```

```
                                   INPUT DATA
                            TURNING CIRCLE MANOEUVRE
*****************************************************************************************
                    DESCRIPTION                                VALUE            UNITS
-----------------------------------------------------------------------------------------
LENGTH BETWEEN PERPENDICULARS
LENGTH ON WATERLINE                                           218.80           METERS
BREADTH                                                       218.80           METERS
DRAFT AFT                                                      23.12           METERS
DRAFT FWD                                                       7.93           METERS
DISPLACEMENT                                                    7.93           METERS
BLOCK COEFFICIENT                                           35640.00           TONNES
MIDSHIP SECTION COEFFICIENT                                     0.88           -----
WATERPLANE COEFFICIENT                                          1.00           -----
RUDDER LATERAL AREA                                             0.91           -----
PROPELLER DIAMETER                                             25.1           SQ. METERS
PROPELLER PITCH/DIAMETER RATIO                                  5.70           METERS
PROPELLER EXPANDED BLADE AREA RATIO                             0.96           -----
SHAFT HORSEPOWER                                                0.50           -----
                                                             5400.0             KW
*****************************************************************************************
                              SHIP SPEED - POWER DATA
SPEED       WAVE       APPEND     BULB BOW    TRANSOM      CORR.     FRICTION     TOTAL      EFFECTIVE
(KNOTS)    RESIST      RESIST      RESIST      RESIST      RESIST     RESIST      RESIST    HORSEPOWER
            (KN)        (KN)        (KN)        (KN)        (KN)       (KN)        (KN)        (KW)
*****************************************************************************************
10.0    0.528E+01   0.332E+01   0.105E+02   0.000E+00   0.364E+02   0.153E+03   0.253E+03   0.130E+04
11.0    0.128E+02   0.400E+01   0.121E+02   0.000E+00   0.440E+02   0.183E+03   0.310E+03   0.175E+04
12.0    0.269E+02   0.473E+01   0.136E+02   0.000E+00   0.524E+02   0.216E+03   0.376E+03   0.232E+04
13.0    0.507E+02   0.553E+01   0.151E+02   0.000E+00   0.615E+02   0.251E+03   0.457E+03   0.305E+04
14.0    0.877E+02   0.639E+01   0.165E+02   0.000E+00   0.713E+02   0.288E+03   0.554E+03   0.399E+04
15.0    0.142E+03   0.731E+01   0.178E+02   0.000E+00   0.819E+02   0.328E+03   0.672E+03   0.519E+04
[illegible] [illegible] 0.827E+01 0.190E+02   0.000E+00   0.931E+02   0.370E+03   0.815E+03   0.671E+04
```

```
 17.0   0.314E+03  0.933E+01  0.202E+02  0.000E+00  0.105E+03  0.415E+03  0.985E+03   0.861E+04
 18.0   0.438E+03  0.104E+02  0.213E+02  0.000E+00  0.118E+03  0.462E+03  0.118E+04   0.110E+05
 19.0   0.594E+03  0.116E+02  0.223E+02  0.000E+00  0.131E+03  0.511E+03  0.142E+04   0.139E+05
 20.0   0.777E+03  0.128E+02  0.232E+02  0.000E+00  0.146E+03  0.563E+03  0.169E+04   0.173E+05
WAKE FRACTION =  0.450
THRUST DEDUCTION FRACTION =  0.170
FORM FACTOR OF THE HULL =  0.292
The friction resistance in the above table was
multiplied by (1.+CFORM) to obtain the total
resistance.
*******************************************************************************************************
  TIME      LOCAL       LOCAL        LOCAL          GLOBAL         GLOBAL       YAW ANGLE   ROLL ANGLE   PROPELLER
           X-SPEED     Y-SPEED    SHIP SPEED      X-POSITION     Y-POSITION                               SPEED
 (SECS)    (KNOTS)     (KNOTS)     (KNOTS)         (METERS)       (METERS)      (DEGREES)   (DEGREES)     (RPM)
*******************************************************************************************************
   0.0      10.50        0.00       10.50             0.00           0.00          0.0         0.0        120.0
  10.0      10.84        0.18       10.84            54.95           0.19         -0.4        -0.1        120.3
  20.0      10.98        0.71       11.00           111.20           0.89         -3.1         0.0        120.6
  30.0      11.01        1.30       11.09           168.05           0.72         -8.0         0.1        120.7
  40.0      10.96        1.80       11.10           225.08          -2.35        -14.4         0.2        120.6
  50.0      10.83        2.17       11.04           281.55          -9.90        -21.6         0.2        120.4
  60.0      10.64        2.42       10.91           336.50         -22.90        -29.2         0.3        120.2
  70.0      10.43        2.57       10.74           388.90         -41.72        -37.0         0.3        120.0
  80.0      10.20        2.67       10.54           437.78         -66.29        -44.9         0.3        119.7
  90.0       9.97        2.72       10.33           482.34         -96.20        -52.8         0.3        119.5
 100.0       9.74        2.74       10.12           521.89        -130.84        -60.6         0.3        119.3
 110.0       9.53        2.74        9.91           555.93        -169.48        -68.4         0.3        119.1
 120.0       9.32        2.73        9.72           584.10        -211.34        -76.1         0.3        118.9
 130.0       9.13        2.72        9.53           606.17        -255.59        -83.8         0.3        118.7
 140.0       8.95        2.70        9.35           622.04        -301.43        -91.4         0.3        118.5
 150.0       8.78        2.68        9.18           631.72        -348.04        -99.0         0.3        118.3
 160.0       8.62        2.67        9.02           635.31        -394.67       -106.4         0.3        118.2
```

170.0	8.47	2.65	8.87	633.00	-440.59	-113.9	0.3	118.1
180.0	8.33	2.63	8.73	625.03	-485.13	-121.3	0.2	117.9
190.0	8.20	2.61	8.60	611.74	-527.66	-128.6	0.2	117.8
200.0	8.08	2.59	8.48	593.52	-567.61	-135.9	0.2	117.7
210.0	7.96	2.58	8.37	570.79	-604.47	-143.1	0.2	117.6
220.0	7.86	2.56	8.26	544.03	-637.81	-150.4	0.2	117.5
230.0	7.76	2.55	8.16	513.74	-667.24	-157.5	0.2	117.4
240.0	7.66	2.53	8.07	480.47	-692.43	-164.7	0.2	117.3
250.0	7.58	2.52	7.99	444.77	-713.15	-171.8	0.2	117.2
260.0	7.50	2.51	7.91	407.21	-729.20	-178.8	0.2	117.2
270.0	7.42	2.50	7.83	368.37	-740.48	-185.9	0.2	117.1
280.0	7.35	2.49	7.76	328.82	-746.92	-192.9	0.2	117.0
290.0	7.28	2.48	7.69	289.13	-748.54	-199.9	0.2	117.0
300.0	7.22	2.47	7.63	249.87	-745.41	-206.9	0.2	116.9
310.0	7.16	2.46	7.57	211.56	-737.66	-213.8	0.2	116.9
320.0	7.11	2.45	7.52	174.73	-725.48	-220.8	0.2	116.8
330.0	7.06	2.44	7.47	139.86	-709.12	-227.7	0.2	116.8
340.0	7.01	2.44	7.42	107.39	-688.87	-234.6	0.2	116.7
350.0	6.96	2.43	7.37	77.75	-665.05	-241.4	0.2	116.7
360.0	6.92	2.42	7.33	51.29	-638.05	-248.3	0.2	116.6
370.0	6.88	2.42	7.29	28.34	-608.28	-255.1	0.2	116.6
380.0	6.84	2.41	7.25	9.16	-576.18	-262.0	0.2	116.6
390.0	6.81	2.41	7.22	-6.03	-542.21	-268.8	0.2	116.5
400.0	6.77	2.40	7.19	-17.06	-506.86	-275.6	0.2	116.5
410.0	6.74	2.40	7.16	-23.83	-470.62	-282.4	0.2	116.5
420.0	6.71	2.39	7.13	-26.29	-433.98	-289.2	0.2	116.4
430.0	6.69	2.39	7.10	-24.45	-397.46	-295.9	0.2	116.4
440.0	6.66	2.39	7.07	-18.37	-361.54	-302.7	0.2	116.4
450.0	6.63	2.38	7.05	-8.16	-326.69	-309.4	0.2	116.4
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-316.2	0.2	116.4

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     470.0      6.59      2.38      7.01        23.89     -262.07     -322.9        0.2        116.3
     480.0      6.57      2.37      6.99        45.25     -233.14     -329.6        0.2        116.3
     490.0      6.55      2.37      6.97        69.77     -206.96     -336.4        0.2        116.3
     500.0      6.53      2.37      6.95        97.10     -183.88     -343.1        0.2        116.3
     510.0      6.52      2.37      6.93       126.85     -164.18     -349.8        0.2        116.3
     520.0      6.50      2.36      6.92       158.62     -148.12     -356.5        0.2        116.3
     530.0      6.48      2.36      6.90       191.97     -135.88     -363.2        0.2        116.2
     540.0      6.47      2.36      6.89       226.43     -127.62     -369.9        0.2        116.2
 END OF TURNING CIRCLE MANOEUVRE

                             RESULTS FROM TIME SIMULATION ANALYSIS
                                  TURNING CIRCLE MANOEUVRE
 *******************************************************************************
                  DESCRIPTION                                 VALUE            UNITS
 -------------------------------------------------------------------------------
 STEADY TURNING SPEED                                          6.91            KNOTS
 NON-DIMENSIONAL ADVANCE (ADVANCE/LPP)                         2.84            -----
 NON-DIMENSIONAL TRANSFER (TRANSFER/LPP)                       1.36            -----
 NON-DIMENSIONAL TACTICAL DIAMETER (TAC. DIA./LPP)             3.34            -----
 NON-DIMENSIONAL STEADY TURNING DIAMETER (STDY. DIA./LPP)      2.70            -----
 *******************************************************************************

                             RESULTS FROM THE EMPIRICAL ANALYSIS
                                  TURNING CIRCLE MANOEUVRE
 *******************************************************************************
                  DESCRIPTION                                 VALUE            UNITS
 -------------------------------------------------------------------------------
 STEADY TURNING SPEED                                          4.49            KNOTS
 NON-DIMENSIONAL ADVANCE (ADVANCE/LPP)                         3.28            -----
 NON-DIMENSIONAL TRANSFER (TRANSFER/LPP)                       1.81            -----
 NON-DIMENSIONAL TACTICAL DIAMETER (TAC. DIA./LPP)             3.77            -----
```

6

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NON-DIMENSIONAL STEADY TURNING DIAMETER (STDY. DIA./LPP)              3.21                -----
 STANDARD DEVIATION OF (VST/VX1) = 0.185
 STANDARD DEVIATION OF (ADV/LPP) = 0.162
 STANDARD DEVIATION OF (TR/LPP) = 0.170
 STANDARD DEVIATION OF (TACDIA/LPP) = 0.111
 STANDARD DEVIATION OF (STDYDIA/LPP) = 0.244
MESSAGES FOR EMPIRICAL TURNING CIRCLE ANALYSIS
-----------------------------------------------
 BLOCK COEFFICIENT IS OUTSIDE THE RANGE OF (.56 <= CB <= .87)
 RATIO (B/LPP) IS OUTSIDE THE RANGE OF (.11 <= RATIO <= .18)
*******************************************************************************************

                                       CRASH STOP MANOEUVRE
*******************************************************************************************
                   DESCRIPTION
-----------------------------------------------------------VALUE                 UNITS
INITIAL SPEED OF SHIP                                      -------------------------------
INITIAL RESISTANCE OF SHIP                                  12.50                KNOTS
MAXIMUM ASTERN THRUST                                      416.5                  KN
NON-DIMENSIONAL HEAD REACH (REACH/LPP)                     326.8                  KN
                                                             6.79                -----
*******************************************************************************************
```

```
XXXXXXXXXX   9999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999
XXXXXXXXXX   99999999999999999999999999  Digital Equipment Corporation - VAX/VMS Version V4.6  99999999999999999999999999   XXXXXXXXXX
XXXXXXXXXX   9999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999   XXXXXXXXXX
                                                                                                              XXXXXXXXXX

                               L       AAA   N   N  TTTTT   OOO    SSSS
                               L      A   A  N   N    T    O   O  S
                               L      A   A  NN  N    T    O   O  S
                               L      A   A  N N N    T    O   O   SSS
                               L      AAAAA  N  NN    T    O   O      S
                               L      A   A  N   N    T    O   O      S
                               LLLLL  A   A  N   N    T     OOO   SSSS

   AAAAAA    LL            GGGGGGGG    OOOOOO    LL                11      000000    ZZZZZZZZZZ  IIIIII    GGGGGGGG
   AAAAAA    LL            GGGGGGGG    OOOOOO    LL                11      000000    ZZZZZZZZZZ  IIIIII    GGGGGGGG
 AA      AA  LL          GG          OO      OO  LL              1111    00      00          ZZ    II    GG
 AA      AA  LL          GG          OO      OO  LL              1111    00    0000          ZZ    II    GG
 AA      AA  LL          GG          OO      OO  LL                11    00    0000        ZZ      II    GG
 AA      AA  LL          GG          OO      OO  LL                11    00  00  00        ZZ      II    GG
 AA      AA  LL          GG          OO      OO  LL                11    00  00  00      ZZ        II    GG
 AA      AA  LL          GG          OO      OO  LL                11    0000    00      ZZ        II    GG
 AAAAAAAAAA  LL          GG  GGGGGG  OO      OO  LL                11    0000    00    ZZ          II    GG  GGGGGG
 AAAAAAAAAA  LL          GG  GGGGGG  OO      OO  LL                11    00      00    ZZ          II    GG  GGGGGG
 AA      AA  LL          GG      GG  OO      OO  LL                11    00      00  ZZ            II    GG      GG
 AA      AA  LL          GG      GG  OO      OO  LL                11    00      00  ZZ            II    GG      GG
 AA      AA  LL          GG      GG  OO      OO  LL                11    00      00  ZZ            II    GG      GG
 AA      AA  LL          GG      GG  OO      OO  LL                11    00      00  ZZ            II    GG      GG
 AA      AA  LLLLLLLLLL    GGGGGG      OOOOOO    LLLLLLLLLL      111111    000000    ZZZZZZZZZZ  IIIIII    GGGGGG
 AA      AA  LLLLLLLLLL    GGGGGG      OOOOOO    LLLLLLLLLL      111111    000000    ZZZZZZZZZZ  IIIIII    GGGGGG

                               DDDDDDDD      AAAAAA    TTTTTTTTTT    ;;;;        11
                               DDDDDDDD      AAAAAA    TTTTTTTTTT    ;;;;        11
                               DD      DD  AA      AA      TT        ;;;;      1111
                               DD      DD  AA      AA      TT        ;;;;      1111
                               DD      DD  AA      AA      TT                    11
                               DD      DD  AA      AA      TT                    11
                               DD      DD  AA      AA      TT        ;;;;        11
                               DD      DD  AA      AA      TT        ;;;;        11
                               DD      DD  AAAAAAAAAA      TT        ;;;;        11
                               DD      DD  AAAAAAAAAA      TT        ;;;;        11
                               DD      DD  AA      AA      TT          ;;        11
                               DD      DD  AA      AA      TT          ;;        11
                        ....   DD      DD  AA      AA      TT                    11
                        ....   DD      DD  AA      AA      TT                    11
                        ....   DDDDDDDD    AA      AA      TT        ;;        111111
                        ....   DDDDDDDD    AA      AA      TT        ;;        111111

File _DUA1:[LANTOS]ALGOL10ZIG.DAT;1 (823,167,0), last revised on 29-JUL-1988 13:25, is a 1 block sequential file owned by UIC
[QANDM,LANTOS].  The records are variable length with implied (CR) carriage control.  The longest record is 62 bytes.

Job ALGOB-15BPIR (221) queued to SYS$PRINT on 28-SEP-1988 10:14 by user LANTOS, UIC [QANDM,LANTOS], under account QANDM at priority
100, started on printer _TXA3: on 28-SEP-1988 10:25 from queue SYS$PRINT.

XXXXXXXXXX   9999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999   XXXXXXXXXX
XXXXXXXXXX   99999999999999999999999999  Digital Equipment Corporation - VAX/VMS Version V4.6  99999999999999999999999999   XXXXXXXXXX
XXXXXXXXXX   9999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999   XXXXXXXXXX
```

```
1000.,1.14E-6,1,14.18,3.268E5
218.8,218.8,23.12,7.93,7.93,0.88,0.996,0.914,3.564E7
0.,0.,0.,0.,5.4,0.,0.,0.,2.,0.,0.,0.,0.,0.45,0.
-110.,6.28,0.45,25.1,3.35,1.57,2.52,3.,0.,11,150.,0.,0,1,0.005
2.134,6.878,5.488,1
50.2,1.4
2,4000.,1.,10.,10,5.7,0.96,0.5,4,5.4E6,2
-108.4,7.93,6.43,1,1,3.15,1.,3,5.
```

```
0000000000  00000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000  0000000000
0000000000  0000000000000000000000000  Digital Equipment Corporation - VAX/VMS Version V4.6  0000000000000000000000000  0000000000
0000000000  00000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000  0000000000

                         L       AAA    N   N  TTTTT   OOO    SSSS
                         L      A   A   N   N    T    O   O  S
                         L      A   A   NN  N    T    O   O  S
                         L      A   A   N N N    T    O   O   SSS
                         L      AAAAA   N  NN    T    O   O      S
                         L      A   A   N   N    T    O   O      S
                         LLLLL  A   A   N   N    T     OOO   SSSS

                  SSSSSSSS    IIIIII    MM          MM  UU          UU  LL
                  SSSSSSSS    IIIIII    MM          MM  UU          UU  LL
                SS              II      MMMM      MMMM  UU          UU  LL
                SS              II      MMMM      MMMM  UU          UU  LL
                SS              II      MM  MM  MM  MM  UU          UU  LL
                SS              II      MM  MM  MM  MM  UU          UU  LL
                  SSSSSS        II      MM    MM    MM  UU          UU  LL
                  SSSSSS        II      MM    MM    MM  UU          UU  LL
                        SS      II      MM          MM  UU          UU  LL
                        SS      II      MM          MM  UU          UU  LL
                        SS      II      MM          MM  UU          UU  LL
                        SS      II      MM          MM  UU          UU  LL
                SSSSSSSS      IIIIII    MM          MM  UUUUUUUUUU      LLLLLLLLLL
                SSSSSSSS      IIIIII    MM          MM  UUUUUUUUUU      LLLLLLLLLL

                          OOOOOO      UU          UU  TTTTTTTTTT      ;;;;    888888
                          OOOOOO      UU          UU  TTTTTTTTTT      ;;;;    888888
                        OO      OO    UU          UU      TT          ;;;;  88      88
                        OO      OO    UU          UU      TT                88      88
                        OO      OO    UU          UU      TT                88      88
                        OO      OO    UU          UU      TT                88      88
                        OO      OO    UU          UU      TT          ;;;;    888888
                        OO      OO    UU          UU      TT          ;;;;    888888
                        OO      OO    UU          UU      TT          ;;;;  88      88
                        OO      OO    UU          UU      TT            ;;  88      88
                  ....  OO      OO    UU          UU      TT            ;;  88      88
                  ....  OO      OO    UU          UU      TT            ;;  88      88
                  ....    OOOOOO      UUUUUUUUUU          TT          ;;      888888
                  ....    OOOOOO      UUUUUUUUUU          TT          ;;      888888

File _DUA1:[LANTOS]SIMUL.OUT;8 (87,121,0), last revised on 28-SEP-1988 10:43, is a 27 block sequential file owned by UIC
[GANDM,LANTOS].  The records are variable length with FORTRAN (FTN) carriage control.  The longest record is 116 bytes.

Job SIMUL (226) queued to SYS$PRINT on 28-SEP-1988 10:52 by user LANTOS, UIC [GANDM,LANTOS], under account GANDM at priority 100,
started on printer _TXA3: on 28-SEP-1988 11:00 from queue SYS$PRINT.

0000000000  00000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000  0000000000
0000000000  0000000000000000000000000  Digital Equipment Corporation - VAX/VMS Version V4.6  0000000000000000000000000  0000000000
0000000000  00000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000  0000000000
```

```
                                   INPUT DATA
                                ZIGZAG MANOEUVRE
***********************************************************************************
                    DESCRIPTION                        VALUE             UNITS
-----------------------------------------------------------------------------------
LENGTH BETWEEN PERPENDICULARS
LENGTH ON WATERLINE                                   218.80             METERS
BREADTH                                               218.80             METERS
DRAFT AFT                                              23.12             METERS
DRAFT FWD                                               7.93             METERS
DISPLACEMENT                                            7.93             METERS
BLOCK COEFFICIENT                                   35640.00             TONNES
MIDSHIP SECTION COEFFICIENT                             0.88             -----
WATERPLANE COEFFICIENT                                  1.00             -----
RUDDER LATERAL AREA                                     0.91             -----
PROPELLER DIAMETER                                     25.1            SQ. METERS
PROPELLER PITCH/DIAMETER RATIO                          5.70             METERS
PROPELLER EXPANDED BLADE AREA RATIO                     0.96             -----
SHAFT HORSEPOWER                                        0.50             -----
***********************************************************************************
                                                      5400.0               KW
***********************************************************************************
                         SHIP SPEED - POWER DATA
SPEED     WAVE       APPEND     BULB BOW    TRANSOM      CORR.     FRICTION     TOTAL      EFFECTIVE
(KNOTS)   RESIST     RESIST      RESIST      RESIST      RESIST     RESIST      RESIST     HORSEPOWER
           (KN)       (KN)        (KN)        (KN)        (KN)       (KN)        (KN)        (KW)
***********************************************************************************
 10.0   0.528E+01  0.332E+01  0.105E+02  0.000E+00  0.364E+02  0.153E+03  0.253E+03  0.130E+04
 11.0   0.128E+02  0.400E+01  0.121E+02  0.000E+00  0.440E+02  0.183E+03  0.310E+03  0.175E+04
 12.0   0.269E+02  0.473E+01  0.136E+02  0.000E+00  0.524E+02  0.216E+03  0.376E+03  0.232E+04
 13.0   0.507E+02  0.553E+01  0.151E+02  0.000E+00  0.615E+02  0.251E+03  0.457E+03  0.305E+04
 14.0   0.877E+02  0.639E+01  0.165E+02  0.000E+00  0.713E+02  0.288E+03  0.554E+03  0.399E+04
 15.0   0.142E+03  0.731E+01  0.178E+02  0.000E+00  0.819E+02  0.328E+03  0.672E+03  0.519E+04
 16[illegible] 0[illegible]E+03 [illegible].82[illegible] [illegible]0E+[illegible] 0.0[illegible]00 [illegible]931E[illegible] 0[illegible]E+03 [illegible].81[illegible]E+03 0.[illegible]71E+04
```

```
   17.0   0.314E+03   0.933E+01   0.202E+02   0.000E+00   0.105E+03   0.415E+03   0.985E+03    0.861E+04
   18.0   0.438E+03   0.104E+02   0.213E+02   0.000E+00   0.118E+03   0.462E+03   0.118E+04    0.110E+05
   19.0   0.594E+03   0.116E+02   0.223E+02   0.000E+00   0.131E+03   0.511E+03   0.142E+04    0.139E+05
   20.0   0.777E+03   0.128E+02   0.232E+02   0.000E+00   0.146E+03   0.563E+03   0.169E+04    0.173E+05
 WAKE FRACTION =  0.450
 THRUST DEDUCTION FRACTION =  0.170
 FORM FACTOR OF THE HULL =  0.292
 The friction resistance in the above table was
 multiplied by (1.+CFORM) to obtain the total
 resistance.
 ****************************************************************************************************
   TIME      LOCAL      LOCAL       LOCAL          GLOBAL         GLOBAL       YAW ANGLE   ROLL ANGLE   PROPELLER
            X-SPEED    Y-SPEED   SHIP SPEED     X-POSITION     Y-POSITION                               SPEED
  (SECS)    (KNOTS)    (KNOTS)    (KNOTS)        (METERS)       (METERS)     (DEGREES)    (DEGREES)     (RPM)
 ****************************************************************************************************
     0.0     10.50       0.00      10.50            0.00           0.00          0.0          0.0        120.0
    10.0     10.87      -0.14      10.87           54.97          -0.17          0.4          0.0        120.3
    20.0     11.21      -0.40      11.22          111.77          -0.47          1.9          0.0        120.7
    30.0     11.52      -0.69      11.54          170.33          -0.05          4.5          0.0        121.0
    40.0     11.80      -0.97      11.84          230.46           2.06          7.8         -0.1        121.3
    50.0     12.06      -1.16      12.11          291.90           6.87         11.6         -0.2        121.6
 RUDDER ANGLE IS  -10.00000

    60.0     12.32      -1.02      12.36          354.22          15.63         14.5         -0.2        121.8
    70.0     12.60      -0.81      12.62          417.23          28.09         16.1         -0.2        122.2
    80.0     12.89      -0.56      12.90          481.06          43.38         16.9         -0.1        122.5
    90.0     13.18      -0.29      13.18          545.85          60.75         16.8         -0.1        122.8
   100.0     13.46       0.01      13.46          611.77          79.44         15.9         -0.1        123.1
   110.0     13.73       0.34      13.73          679.03          98.62         14.3          0.0        123.4
   120.0     13.96       0.67      13.98          747.83         117.30         11.8          0.1        123.7
   130.0     14.17       0.99      14.20          818.29         134.35          8.5          0.1        123.9
   140.0     14.33       1.27      14.39          890.44         148.60          4.6          0.2        124.1
```

```
     150.0     14.45      1.52     14.53      964.10     158.90      0.1      0.2     124.2
     160.0     14.53      1.72     14.64     1038.93     164.20     -4.9      0.3     124.3
     170.0     14.59      1.85     14.70     1114.39     163.63    -10.2      0.3     124.3
 RUDDER ANGLE IS    10.00000

     180.0     14.66      1.68     14.76     1189.80     156.25    -14.8      0.4     124.4
     190.0     14.80      1.37     14.86     1264.66     142.36    -17.8      0.3     124.6
     200.0     14.97      1.05     15.01     1339.09     123.46    -19.8      0.2     124.8
     210.0     15.16      0.73     15.18     1413.33     100.76    -20.8      0.2     125.0
     220.0     15.37      0.40     15.37     1487.69      75.34    -21.0      0.1     125.3
     230.0     15.57      0.03     15.57     1562.52      48.24    -20.3      0.1     125.5
     240.0     15.75     -0.37     15.76     1638.19      20.55    -18.5      0.0     125.7
     250.0     15.91     -0.77     15.93     1715.11      -6.43    -15.8     -0.1     125.9
     260.0     16.02     -1.15     16.06     1793.57     -31.23    -12.2     -0.1     126.0
     270.0     16.08     -1.48     16.15     1873.70     -52.32     -7.8     -0.2     126.1
     280.0     16.10     -1.76     16.19     1955.35     -68.25     -2.7     -0.3     126.1
     290.0     16.07     -1.97     16.19     2038.08     -77.76      2.9     -0.3     126.1
     300.0     16.01     -2.14     16.15     2121.22     -79.85      8.9     -0.4     126.0
 RUDDER ANGLE IS   -10.00000

     310.0     15.95     -2.07     16.09     2203.88     -73.70     14.7     -0.5     125.9
     320.0     15.97     -1.74     16.07     2285.23     -59.12     19.0     -0.4     126.0
     330.0     16.06     -1.41     16.12     2365.17     -37.81     21.9     -0.3     126.1
     340.0     16.18     -1.10     16.21     2443.96     -11.27     24.0     -0.2     126.2
     350.0     16.32     -0.79     16.34     2521.90      19.31     25.3     -0.2     126.4
     360.0     16.48     -0.48     16.49     2599.38      52.85     25.8     -0.1     126.6
     370.0     16.64     -0.14     16.64     2676.83      88.35     25.5     -0.1     126.7
     380.0     16.79      0.23     16.79     2754.72     124.76     24.2      0.0     126.9
     390.0     16.91      0.62     16.92     2833.56     160.87     22.0      0.1     127.1
     400.0     17.00      1.01     17.03     2913.84     195.28     18.8      0.1     127.2
     4[redacted]     [redacted]04      1[redacted]     [redacted].10     [redacted]5.9     [redacted].46     14.7      0.2     127.2
     420.0     17.04     1.66     17.12     3079.87     252.87      9.9     0.3     127.2
     430.0     16.99     1.90     17.10     3165.53     273.09      4.6     0.3     127.2
     440.0     16.91     2.09     17.03     3252.37     285.93     -1.3     0.4     127.1
     450.0     16.79     2.23     16.94     3339.61     290.49     -7.4     0.4     126.9
     460.0     16.69     2.19     16.83     3426.32     286.10    -13.5     0.5     126.8
RUDDER ANGLE IS    10.00000

     470.0     16.65     1.83     16.75     3511.55     272.54    -18.0     0.4     126.8
     480.0     16.70     1.46     16.76     3595.12     251.61    -21.1     0.3     126.8
     490.0     16.79     1.11     16.83     3677.31     225.11    -23.2     0.3     126.9
     500.0     16.91     0.77     16.92     3758.51     194.44    -24.4     0.2     127.1
     510.0     17.04     0.41     17.04     3839.16     160.85    -24.7     0.1     127.2
     520.0     17.17     0.02     17.17     3919.78     125.54    -23.9     0.1     127.4
     530.0     17.29    -0.41     17.30     4000.90      89.75    -22.2     0.0     127.5
     540.0     17.38    -0.84     17.40     4083.09      54.98    -19.4    -0.1     127.6
     550.0     17.42    -1.25     17.46     4166.81      22.87    -15.5    -0.2     127.7
     560.0     17.40    -1.60     17.48     4252.31      -4.83    -10.8    -0.3     127.7
     570.0     17.34    -1.89     17.44     4339.47     -26.49     -5.4    -0.3     127.6
     580.0     17.23    -2.11     17.36     4427.84     -40.71      0.5    -0.4     127.5
     590.0     17.09    -2.28     17.24     4516.65     -46.43      6.8    -0.4     127.3
END OF ZIGZAG SIMULATION


                      RESULTS FROM TIME SIMULATION ANALYSIS
                               ZIGZAG MANOEUVRE
****************************************************************************************
                    DESCRIPTION                              VALUE            UNITS
----------------------------------------------------------------------------------------
OVERSHOOT ANGLE
                                                              6.94           DEGREES
NON-DIMENSIONAL OVERSHOOT WIDTH OF PATH (WIDTH/LPP)           0.73            -----
PERIOD BETWEEN 1st RUDDER CHANGE AND 3rd RUDDER CHANGE      257.0            SECS.
NON-DIMENSIONAL REACH (REACH/LPP)
                                                              4.44            -----
```

13

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**********************************************************************************************

                          RESULTS FROM THE EMPIRICAL ANALYSIS

                               CRASH STOP MANOEUVRE
**********************************************************************************************
                 DESCRIPTION
                                                      VALUE                      UNITS
INITIAL SPEED OF SHIP
INITIAL RESISTANCE OF SHIP                            12.50                      KNOTS
MAXIMUM ASTERN THRUST                                416.5                        KN
NON-DIMENSIONAL HEAD REACH (REACH/LPP)               326.8                        KN
                                                       6.79                      -----
**********************************************************************************************
```

74

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YYYYYYYYYY   99999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999
YYYYYYYYYY   9999999999999999999999999  Digital Equipment Corporation - VAX/VMS Version V4.6  9999999999999999999999999   YYYYYYYYYY
YYYYYYYYYY   99999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999   YYYYYYYYYY
                                                                                                                YYYYYYYYYY

                        L       AAA   N   N  TTTTT   OOO   SSSS
                        L      A   A  N   N    T    O   O S
                        L      A   A  NN  N    T    O   O S
                        L      A   A  N N N    T    O   O  SSS
                        L      AAAAA  N  NN    T    O   O     S
                        L      A   A  N   N    T    O   O     S
                        LLLLL  A   A  N   N    T     OOO  SSSS

  AAAAAA    LL           GGGGGGGG    OOOOOO    LL           222222     000000    ZZZZZZZZZZ  IIIIII    GGGGGGGG
  AAAAAA    LL           GGGGGGGG    OOOOOO    LL           222222     000000    ZZZZZZZZZZ  IIIIII    GGGGGGGG
AA      AA  LL         GG          OO      OO  LL         22      22 00      00          ZZ    II    GG
AA      AA  LL         GG          OO      OO  LL         22      22 00      00          ZZ    II    GG
AA      AA  LL         GG          OO      OO  LL                 22 00    0000        ZZ      II    GG
AA      AA  LL         GG          OO      OO  LL                 22 00    0000        ZZ      II    GG
AA      AA  LL         GG    GGGGGG OO     OO  LL               22   00  00  00      ZZ        II    GG    GGGGGG
AA      AA  LL         GG    GGGGGG OO     OO  LL               22   00  00  00      ZZ        II    GG    GGGGGG
AAAAAAAAAA  LL         GG        GG OO     OO  LL             22     0000    00    ZZ          II    GG        GG
AAAAAAAAAA  LL         GG        GG OO     OO  LL             22     0000    00    ZZ          II    GG        GG
AA      AA  LL         GG        GG OO     OO  LL           22       00      00  ZZ            II    GG        GG
AA      AA  LL         GG        GG OO     OO  LL           22       00      00  ZZ            II    GG        GG
AA      AA  LLLLLLLLLL   GGGGGG      OOOOOO    LLLLLLLLLL   2222222222 000000    ZZZZZZZZZZ  IIIIII    GGGGGG
AA      AA  LLLLLLLLLL   GGGGGG      OOOOOO    LLLLLLLLLL   2222222222 000000    ZZZZZZZZZZ  IIIIII    GGGGGG

                        DDDDDDDD     AAAAAA    TTTTTTTTTT    ;;;;         11
                        DDDDDDDD     AAAAAA    TTTTTTTTTT    ;;;;         11
                        DD      DD AA      AA      TT        ;;;;       1111
                        DD      DD AA      AA      TT        ;;;;       1111
                        DD      DD AA      AA      TT                     11
                        DD      DD AA      AA      TT                     11
                        DD      DD AA      AA      TT        ;;;;         11
                        DD      DD AA      AA      TT        ;;;;         11
                        DD      DD AAAAAAAAAA      TT        ;;;;         11
                        DD      DD AAAAAAAAAA      TT        ;;;;         11
                  ....  DD      DD AA      AA      TT          ;;         11
                  ....  DD      DD AA      AA      TT          ;;         11
                  ....  DDDDDDDD   AA      AA      TT        ;;         111111
                  ....  DDDDDDDD   AA      AA      TT        ;;         111111

File  DUA1:[LANTOS]ALGOL20ZIG.DAT;1 (1044,30,0), last revised on 29-JUL-1988 13:27, is a 1 block sequential file owned by UIC
[GANDM,LANTOS].  The records are variable length with implied (CR) carriage control.  The longest record is 62 bytes.

Job ALGOB-158PIR (221) queued to SYS$PRINT on 28-SEP-1988 10:14 by user LANTOS, UIC [GANDM,LANTOS], under account GANDM at priority
100, started on printer _TXA3: on 28-SEP-1988 10:26 from queue SYS$PRINT.

YYYYYYYYYY   99999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999
YYYYYYYYYY   9999999999999999999999999  Digital Equipment Corporation - VAX/VMS Version V4.6  9999999999999999999999999   YYYYYYYYYY
YYYYYYYYYY   99999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999   YYYYYYYYYY
                                                                                                                YYYYYYYYYY
```

75

```
1000.,1.14E-6,1,14,18,3.268E5
218.8,218.8,23.12,7.93,7.93,0.88,0.996,0.914,3.564E7
0.,0.,0.,0.,5.4,0.,0.,0.,2.,0.,0.,0.,0.,0.,0.45,0.
-110.,6.28,0.45,25.1,3.35,1.57,2.52,3.,0.,11,150.,0.,0,1,0.005
2.134,6.878,5.488,1
50.2,1.4
2,4000.,1.,20.,10,5.7,0.96,0.5,4,5.4E6,2
-108.4,7.93,6.43,1,1,3.15,1.,3,5.
```

```
NNNNNNNNNNN   00000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000   NNNNNNNNNNN
NNNNNNNNNNN   000000000000000000000000  Digital Equipment Corporation - VAX/VMS Version V4.6  000000000000000000000000   NNNNNNNNNNN
NNNNNNNNNNN   00000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000   NNNNNNNNNNN

                                             L       AAA   N   N  TTTTT   OOO    SSSS
                                             L      A   A  N   N    T    O   O  S
                                             L      A   A  NN  N    T    O   O  S
                                             L      A   A  N N N    T    O   O   SSS
                                             L      AAAAA  N  NN    T    O   O      S
                                             L      A   A  N   N    T    O   O      S
                                             LLLLL  A   A  N   N    T     OOO   SSSS

                                      SSSSSSSS    IIIIII    MM      MM  UU      UU  LL
                                      SSSSSSSS    IIIIII    MM      MM  UU      UU  LL
                                    SS              II      MMMM  MMMM  UU      UU  LL
                                    SS              II      MMMM  MMMM  UU      UU  LL
                                    SS              II      MM  MM  MM  UU      UU  LL
                                    SS              II      MM  MM  MM  UU      UU  LL
                                      SSSSSS        II      MM      MM  UU      UU  LL
                                      SSSSSS        II      MM      MM  UU      UU  LL
                                            SS      II      MM      MM  UU      UU  LL
                                            SS      II      MM      MM  UU      UU  LL
                                            SS      II      MM      MM  UU      UU  LL
                                            SS      II      MM      MM  UU      UU  LL
                                    SSSSSSSS      IIIIII    MM      MM  UUUUUUUUUU  LLLLLLLLLL
                                    SSSSSSSS      IIIIII    MM      MM  UUUUUUUUUU  LLLLLLLLLL

                                            OOOOOO    UU      UU  TTTTTTTTTT      ;;;;      999999
                                            OOOOOO    UU      UU  TTTTTTTTTT      ;;;;      999999
                                          OO      OO  UU      UU      TT        ;;;;    99      99
                                          OO      OO  UU      UU      TT        ;;;;    99      99
                                          OO      OO  UU      UU      TT                  99      99
                                          OO      OO  UU      UU      TT                  99      99
                                          OO      OO  UU      UU      TT        ;;;;      99999999
                                          OO      OO  UU      UU      TT        ;;;;      99999999
                                          OO      OO  UU      UU      TT        ;;;;            99
                                          OO      OO  UU      UU      TT        ;;;;            99
                                          OO      OO  UU      UU      TT            ;;          99
                                          OO      OO  UU      UU      TT            ;;          99
                                            OOOOOO    UUUUUUUUUU      TT        ;;        999999
                                            OOOOOO    UUUUUUUUUU      TT        ;;        999999


File _DUA1:[LANTOS]SIMUL.OUT;9 (190,106,0), last revised on 28-SEP-1988 10:44, is a 28 block sequential file owned by UIC
[GANDM,LANTOS].  The records are variable length with FORTRAN (FTN) carriage control.  The longest record is 116 bytes.

Job SIMUL (226) queued to SYS$PRINT on 28-SEP-1988 10:52 by user LANTOS, UIC [GANDM,LANTOS], under account GANDM at priority 100,
started on printer _TXA3: on 28-SEP-1988 10:59 from queue SYS$PRINT.

NNNNNNNNNNN   00000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000   NNNNNNNNNNN
NNNNNNNNNNN   000000000000000000000000  Digital Equipment Corporation - VAX/VMS Version V4.6  000000000000000000000000   NNNNNNNNNNN
NNNNNNNNNNN   00000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000   NNNNNNNNNNN
```

```
                                        INPUT DATA
                                     ZIGZAG MANOEUVRE
**************************************************************************************************
                      DESCRIPTION                                  VALUE                UNITS
LENGTH BETWEEN PERPENDICULARS
LENGTH ON WATERLINE                                               218.80               METERS
BREADTH                                                           218.80               METERS
DRAFT AFT                                                          23.12               METERS
DRAFT FWD                                                           7.93               METERS
DISPLACEMENT                                                        7.93               METERS
BLOCK COEFFICIENT                                               35640.00               TONNES
MIDSHIP SECTION COEFFICIENT                                         0.88               -----
WATERPLANE COEFFICIENT                                              1.00               -----
RUDDER LATERAL AREA                                                 0.91               -----
PROPELLER DIAMETER                                                 25.1                SQ. METERS
PROPELLER PITCH/DIAMETER RATIO                                      5.70               METERS
PROPELLER EXPANDED BLADE AREA RATIO                                 0.96               -----
SHAFT HORSEPOWER                                                    0.50               -----
*****************************************************************5400.0****************KW
**************************************************************************************************
                              SHIP SPEED - POWER DATA
SPEED      WAVE       APPEND     BULB BOW    TRANSOM      CORR.      FRICTION     TOTAL      EFFECTIVE
(KNOTS)   RESIST      RESIST      RESIST     RESIST      RESIST       RESIST     RESIST     HORSEPOWER
           (KN)        (KN)        (KN)       (KN)        (KN)         (KN)       (KN)         (KW)
**************************************************************************************************
 10.0   0.528E+01   0.332E+01   0.105E+02   0.000E+00   0.364E+02   0.153E+03   0.253E+03   0.130E+04
 11.0   0.128E+02   0.400E+01   0.121E+02   0.000E+00   0.440E+02   0.183E+03   0.310E+03   0.175E+04
 12.0   0.269E+02   0.473E+01   0.136E+02   0.000E+00   0.524E+02   0.216E+03   0.376E+03   0.232E+04
 13.0   0.507E+02   0.553E+01   0.151E+02   0.000E+00   0.615E+02   0.251E+03   0.457E+03   0.305E+04
 14.0   0.877E+02   0.639E+01   0.165E+02   0.000E+00   0.713E+02   0.288E+03   0.554E+03   0.399E+04
 15.0   0.142E+03   0.731E+01   0.178E+02   0.000E+00   0.819E+02   0.328E+03   0.672E+03   0.519E+04
[redacted] 16.[redacted]   0.[redacted]+03 [redacted]829[redacted]   [redacted]E+0[redacted]0.0[redacted]0   [redacted]31E-[redacted]   0.[redacted]+03[redacted]815[redacted]   [redacted]71E+[redacted] [redacted] [redacted] [redacted] [redacted]
```

```
    17. 0    0. 314E+03   0. 933E+01   0. 202E+02   0. 000E+00   0. 105E+03   0. 415E+03   0. 985E+03    0. 861E+04
    18. 0    0. 438E+03   0. 104E+02   0. 213E+02   0. 000E+00   0. 118E+03   0. 462E+03   0. 118E+04    0. 110E+05
    19. 0    0. 594E+03   0. 116E+02   0. 223E+02   0. 000E+00   0. 131E+03   0. 511E+03   0. 142E+04    0. 139E+05
    20. 0    0. 777E+03   0. 128E+02   0. 232E+02   0. 000E+00   0. 146E+03   0. 563E+03   0. 169E+04    0. 173E+05
  WAKE FRACTION =  0. 450

  THRUST DEDUCTION FRACTION =  0. 170

  FORM FACTOR OF THE HULL =  0. 292

  The friction resistance in the above table was
  multiplied by (1. +CFORM) to obtain the total
  resistance.

  ****************************************************************************************************************
    TIME        LOCAL        LOCAL         LOCAL          GLOBAL          GLOBAL       YAW ANGLE   ROLL ANGLE    PROPELLER
               X-SPEED      Y-SPEED     SHIP SPEED      X-POSITION      Y-POSITION                               SPEED
   (SECS)      (KNOTS)      (KNOTS)      (KNOTS)         (METERS)        (METERS)     (DEGREES)    (DEGREES)       (RPM)
  ****************************************************************************************************************
      0. 0      10. 50        0. 00       10. 50            0. 00           0. 00         0. 0         0. 0        120. 0
     10. 0      10. 84       -0. 20       10. 84           54. 95          -0. 21         0. 5         0. 1        120. 3
     20. 0      11. 10       -0. 64       11. 12          111. 44          -0. 80         3. 0         0. 0        120. 7
     30. 0      11. 30       -1. 11       11. 36          169. 28          -0. 34         7. 2        -0. 1        120. 9
     40. 0      11. 44       -1. 53       11. 54          228. 11           2. 83        12. 5        -0. 1        121. 0
     50. 0      11. 51       -1. 86       11. 66          287. 35          10. 14        18. 6        -0. 2        121. 1
     60. 0      11. 60       -1. 96       11. 76          346. 21          22. 79        24. 8        -0. 4        121. 1
 RUDDER ANGLE IS  -20. 00000

     70. 0      11. 74       -1. 65       11. 85          403. 8[illegible]  41. 90      29. 3        -0. 4        121. 3
     80. 0      11. 93       -1. 20       11. 99          459. 95          66. 52        31. 5        -0. 3        121. 6
     90. 0      12. 17       -0. 73       12. 19          515. 21          95. 02        32. 0        -0. 2        121. 9
    100. 0      12. 42       -0. 20       12. 42          570. 36         126. 09        30. 9        -0. 1        122. 2
    110. 0      12. 65        0. 36       12. 66          626. 14         158. 52        28. 4         0. 0        122. 4
    120. 0      12. 83        0. 91       12. 87          683. 29         190. 87        24. 6         0. 0        122. 5
    130. 0      12. 95        1. 40       13. 03          742. 46         221. 48        19. 7         0. 1        122. 6
    140. 0      13. 00        1. 78       13. 12          803. 99         248. 66        13. 9         0. 2        122. 7
   150. 0     12. 98     2. 08     13. 15      867. 81     270. 86      7. 5      0. 3     122. 6
   160. 0     12. 93     2. 28     13. 13      933. 47     286. 82      0. 7      0. 3     122. 5
   170. 0     12. 84     2. 42     13. 07     1000. 23     295. 67     -6. 4      0. 3     122. 4
   180. 0     12. 73     2. 51     12. 98     1067. 18     296. 85    -13. 5      0. 4     122. 3
   190. 0     12. 62     2. 51     12. 86     1133. 30     290. 13    -20. 7      0. 4     122. 2
   200. 0     12. 63     2. 30     12. 84     1197. 64     275. 20    -27. 1      0. 5     122. 2
RUDDER ANGLE IS    20. 00000

   210. 0     12. 69     1. 77     12. 81     1259. 53     252. 51    -31. 1      0. 4     122. 4
   220. 0     12. 85     1. 21     12. 91     1319. 18     224. 02    -32. 9      0. 3     122. 6
   230. 0     13. 06     0. 64     13. 07     1377. 63     191. 70    -32. 9      0. 2     122. 9
   240. 0     13. 27     0. 01     13. 27     1435. 84     157. 04    -31. 2      0. 1     123. 1
   250. 0     13. 44    -0. 64     13. 46     1494. 73     121. 55    -27. 9      0. 0     123. 3
   260. 0     13. 55    -1. 24     13. 61     1555. 23      87. 06    -23. 2     -0. 1     123. 3
   270. 0     13. 57    -1. 73     13. 68     1617. 97      55. 55    -17. 4     -0. 2     123. 3
   280. 0     13. 53    -2. 09     13. 69     1683. 14      28. 89    -10. 9     -0. 3     123. 2
   290. 0     13. 42    -2. 35     13. 63     1750. 42       8. 64     -3. 8     -0. 3     123. 1
   300. 0     13. 28    -2. 52     13. 52     1819. 06      -4. 07      3. 6     -0. 4     122. 9
   310. 0     13. 12    -2. 62     13. 38     1888. 08      -8. 56     11. 1     -0. 4     122. 8
   320. 0     12. 95    -2. 68     13. 23     1956. 37      -4. 56     18. 7     -0. 4     122. 6
   330. 0     12. 85    -2. 57     13. 11     2022. 83       8. 06     26. 0     -0. 5     122. 4
RUDDER ANGLE IS   -20. 00000

   340. 0     12. 87    -2. 09     13. 03     2086. 55      29. 40     31. 3     -0. 5     122. 5
   350. 0     12. 97    -1. 54     13. 07     2147. 35      57. 67     34. 2     -0. 3     122. 7
   360. 0     13. 16    -1. 02     13. 20     2206. 21      90. 73     35. 4     -0. 2     122. 9
   370. 0     13. 37    -0. 49     13. 38     2264. 09     127. 04     35. 1     -0. 2     123. 2
   380. 0     13. 57     0. 11     13. 57     2321. 90     165. 30     33. 3     -0. 1     123. 4
   390. 0     13. 74     0. 70     13. 76     2380. 56     204. 09     30. 0      0. 0     123. 5
   400. 0     13. 85     1. 28     13. 90     2440. 98     241. 71     25. 5      0. 1     123. 6
   420.0    13.84     2.05     13.99     2569.30     306.14     13.5      0.3      123.6
   430.0    13.74     2.30     13.94     2637.16     329.64      6.6      0.3      123.4
   440.0    13.61     2.47     13.84     2706.75     345.69     -0.5      0.4      123.3
   450.0    13.46     2.58     13.71     2777.13     353.56     -7.9      0.4      123.1
   460.0    13.30     2.64     13.56     2847.24     352.88    -15.3      0.4      122.9
   470.0    13.17     2.58     13.42     2915.92     343.52    -22.6      0.5      122.8
   480.0    13.17     2.24     13.35     2982.31     325.42    -28.6      0.5      122.8
RUDDER ANGLE IS   20.00000

   490.0    13.23     1.65     13.33     3045.80     299.59    -32.0      0.3      123.0
   500.0    13.38     1.08     13.42     3107.07     268.40    -33.4      0.2      123.2
   510.0    13.57     0.48     13.58     3167.25     233.72    -32.9      0.2      123.4
   520.0    13.76    -0.18     13.76     3227.29     197.09    -30.8      0.1      123.6
   530.0    13.90    -0.83     13.93     3288.22     160.17    -27.1      0.0      123.7
   540.0    13.97    -1.41     14.04     3350.95     124.91    -22.1     -0.1      123.8
   550.0    13.95    -1.88     14.08     3416.05      93.38    -16.0     -0.2      123.7
   560.0    13.86    -2.22     14.04     3483.57      67.46     -9.1     -0.3      123.6
   570.0    13.72    -2.45     13.94     3553.01      48.64     -1.9     -0.4      123.4
   580.0    13.55    -2.60     13.80     3623.52      37.92      5.6     -0.4      123.2
   590.0    13.36    -2.69     13.63     3694.01      35.87     13.3     -0.4      123.0
   600.0    13.17    -2.73     13.45     3763.30      42.63     21.0     -0.4      122.8
END OF ZIGZAG SIMULATION


                          RESULTS FROM TIME SIMULATION ANALYSIS
                                   ZIGZAG MANOEUVRE
*******************************************************************************************
                   DESCRIPTION                                 VALUE              UNITS
-------------------------------------------------------------------------------------------
OVERSHOOT ANGLE                                                12.01             DEGREES
NON-DIMENSIONAL OVERSHOOT WIDTH OF PATH (WIDTH/LPP)             1.30              -----
PERIOD BETWEEN 1st RUDDER CHANGE AND 3rd RUDDER CHANGE        270.0               SECS.
```

```
NON-DIMENSIONAL REACH (REACH/LPP)
                                                                  4.30                      -----
*******************************************************************************************************

                                            RESULTS FROM THE EMPIRICAL ANALYSIS

                                                 CRASH STOP MANOEUVRE
*******************************************************************************************************
                  DESCRIPTION
                                                                  VALUE                     UNITS
INITIAL SPEED OF SHIP
INITIAL RESISTANCE OF SHIP                                        12.50                     KNOTS
MAXIMUM ASTERN THRUST                                            416.5                       KN
NON-DIMENSIONAL HEAD REACH (REACH/LPP)                           326.8                       KN
                                                                   6.79                     -----
*******************************************************************************************************
```

```
ZZZZZZZZZZ    9999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999    ZZZZZZZZZZ
ZZZZZZZZZZ    9999999999999999999999999  Digital Equipment Corporation - VAX/VMS Version V4.6  9999999999999999999999999    ZZZZZZZZZZ
ZZZZZZZZZZ    9999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999    ZZZZZZZZZZ

                                          L      AAA   N   N  TTTTT   OOO    SSSS
                                          L     A   A  N   N    T    O   O  S
                                          L     A   A  NN  N    T    O   O  S
                                          L     A   A  N N N    T    O   O   SSS
                                          L     AAAAA  N  NN    T    O   O      S
                                          L     A   A  N   N    T    O   O      S
                                          LLLLL A   A  N   N    T     OOO   SSSS

  AAAAAA    LL            GGGGGGGG    OOOOOO    LL            333333    5555555555    CCCCCCCC  IIIIII  RRRRRRRR
  AAAAAA    LL            GGGGGGGG    OOOOOO    LL            333333    5555555555    CCCCCCCC  IIIIII  RRRRRRRR
AA      AA  LL          GG          OO      OO  LL          33      33  55          CC            II    RR      RR
AA      AA  LL          GG          OO      OO  LL          33      33  55          CC            II    RR      RR
AA      AA  LL          GG          OO      OO  LL                  33  555555      CC            II    RR      RR
AA      AA  LL          GG          OO      OO  LL                  33  555555      CC            II    RR      RR
AA      AA  LL          GG          OO      OO  LL                33          55    CC            II    RRRRRRRR
AA      AA  LL          GG          OO      OO  LL                33          55    CC            II    RRRRRRRR
AAAAAAAAAA  LL          GG  GGGGGG  OO      OO  LL                  33          55  CC            II    RR  RR
AAAAAAAAAA  LL          GG  GGGGGG  OO      OO  LL                  33          55  CC            II    RR  RR
AA      AA  LL          GG      GG  OO      OO  LL          33      33  55      55  CC            II    RR    RR
AA      AA  LL          GG      GG  OO      OO  LL          33      33  55      55  CC            II    RR    RR
AA      AA  LLLLLLLLLL    GGGGGG      OOOOOO    LLLLLLLLLL    333333      555555      CCCCCCCC  IIIIII  RR      RR
AA      AA  LLLLLLLLLL    GGGGGG      OOOOOO    LLLLLLLLLL    333333      555555      CCCCCCCC  IIIIII  RR      RR

                                    DDDDDDDD      AAAAAA    TTTTTTTTTT    ;;;;      11
                                    DDDDDDDD      AAAAAA    TTTTTTTTTT    ;;;;      11
                                    DD      DD  AA      AA      TT        ;;;;    1111
                                    DD      DD  AA      AA      TT        ;;;;    1111
                                    DD      DD  AA      AA      TT                  11
                                    DD      DD  AA      AA      TT                  11
                                    DD      DD  AA      AA      TT        ;;;;      11
                                    DD      DD  AA      AA      TT        ;;;;      11
                                    DD      DD  AAAAAAAAAA      TT        ;;;;      11
                                    DD      DD  AAAAAAAAAA      TT        ;;;;      11
                                    DD      DD  AA      AA      TT          ;;      11
                                    DD      DD  AA      AA      TT          ;;      11
                                    DDDDDDDD    AA      AA      TT        ;;      111111
                                    DDDDDDDD    AA      AA      TT        ;;      111111

File _DUA1:[LANTOS]ALGOL35CIR.DAT;1 (843,105,0), last revised on 29-JUL-1988 13:24, is a 1 block sequential file owned by UIC
[GANDM,LANTOS].  The records are variable length with implied (CR) carriage control.  The longest record is 62 bytes.

Job ALGOB-15SPIR (221) queued to SYS$PRINT on 28-SEP-1988 10:14 by user LANTOS, UIC [GANDM,LANTOS], under account GANDM at priority
100, started on printer _TXA3: on 28-SEP-1988 10:26 from queue SYS$PRINT.

ZZZZZZZZZZ    9999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999    ZZZZZZZZZZ
ZZZZZZZZZZ    9999999999999999999999999  Digital Equipment Corporation - VAX/VMS Version V4.6  9999999999999999999999999    ZZZZZZZZZZ
ZZZZZZZZZZ    9999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999    ZZZZZZZZZZ
```

```
1000. , 1. 14E-6, 1, 14. 18, 3. 268E5
218. 8, 218. 8, 23. 12, 7. 93, 7. 93, 0. 88, 0. 996, 0. 914, 3. 564E7
0. , 0. , 0. , 0. , 5. 4, 0. , 0. , 0. , 2. , 0. , 0. , 0. , 0. , 0. , 0. 45, 0.
-110. , 6. 28, 0. 45, 25. 1, 3. 35, 1. 57, 2. 52, 3. , 0. , 11, 150. , 0. , 0, 1, 0. 005
2. 134, 6. 878, 5. 488, 1
50. 2, 1. 4
1, 4000. , 1. , 35. , 10, 5. 7, 0. 96, 0. 5, 4, 5. 4E6, 2
-108. 4, 7. 93, 6. 43, 1, 1, 3. 15, 1. , 3, 5.
```

```
MMMMMMMMMM   0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000   MMMMMMMMMM
MMMMMMMMMM   0000000000000000000000000  Digital Equipment Corporation - VAX/VMS Version V4.6  0000000000000000000000000   MMMMMMMMMM
MMMMMMMMMM   0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000   MMMMMMMMMM

                        L        AAA   N   N  TTTTT   OOO    SSSS
                        L       A   A  N   N    T    O   O  S
                        L       A   A  NN  N    T    O   O  S
                        L       A   A  N N N    T    O   O   SSS
                        L       AAAAA  N  NN    T    O   O      S
                        L       A   A  N   N    T    O   O      S
                        LLLLL   A   A  N   N    T     OOO   SSSS

                  SSSSSSSS    IIIIII    MM      MM  UU      UU  LL
                  SSSSSSSS    IIIIII    MM      MM  UU      UU  LL
                SS              II      MMMM  MMMM  UU      UU  LL
                SS              II      MMMM  MMMM  UU      UU  LL
                SS              II      MM  MM  MM  UU      UU  LL
                SS              II      MM  MM  MM  UU      UU  LL
                  SSSSSS        II      MM      MM  UU      UU  LL
                  SSSSSS        II      MM      MM  UU      UU  LL
                        SS      II      MM      MM  UU      UU  LL
                        SS      II      MM      MM  UU      UU  LL
                        SS      II      MM      MM  UU      UU  LL
                        SS      II      MM      MM  UU      UU  LL
                SSSSSSSS      IIIIII    MM      MM  UUUUUUUUUU  LLLLLLLLLL
                SSSSSSSS      IIIIII    MM      MM  UUUUUUUUUU  LLLLLLLLLL

                  OOOOOO    UU      UU  TTTTTTTTTT     ;;;;         11        000000
                  OOOOOO    UU      UU  TTTTTTTTTT     ;;;;         11        000000
                OO      OO  UU      UU      TT         ;;;;       1111      00      00
                OO      OO  UU      UU      TT         ;;;;       1111      00      00
                OO      OO  UU      UU      TT                      11      00    0000
                OO      OO  UU      UU      TT                      11      00    0000
                OO      OO  UU      UU      TT         ;;;;         11      00  00  00
                OO      OO  UU      UU      TT         ;;;;         11      00  00  00
                OO      OO  UU      UU      TT         ;;;;         11      0000    00
                OO      OO  UU      UU      TT         ;;;;         11      0000    00
        . . . . OO      OO  UU      UU      TT           ;;         11      00      00
        . . . . OO      OO  UU      UU      TT           ;;         11      00      00
        . . . .   OOOOOO    UUUUUUUUUU      TT         ;;         111111      000000
        . . . .   OOOOOO    UUUUUUUUUU      TT         ;;         111111      000000

File _DUA1:[LANTOS]SIMUL.OUT;10 (290,132,0), last revised on 28-SEP-1988 10:44, is a 29 block sequential file owned by UIC
[QANDM,LANTOS].  The records are variable length with FORTRAN (FTN) carriage control.  The longest record is 116 bytes.

Job SIMUL (226) queued to SYS$PRINT on 28-SEP-1988 10:52 by user LANTOS, UIC [QANDM,LANTOS], under account QANDM at priority 100,
started on printer _TXA3: on 28-SEP-1988 10:58 from queue SYS$PRINT.

MMMMMMMMMM   0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000   MMMMMMMMMM
MMMMMMMMMM   0000000000000000000000000  Digital Equipment Corporation - VAX/VMS Version V4.6  0000000000000000000000000   MMMMMMMMMM
MMMMMMMMMM   0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000   MMMMMMMMMM
```

```
                                   INPUT DATA
                            TURNING CIRCLE MANOEUVRE
*************************************************************************************************
                    DESCRIPTION                                   VALUE              UNITS
-------------------------------------------------------------------------------------------------
LENGTH BETWEEN PERPENDICULARS
LENGTH ON WATERLINE                                              218.80            METERS
BREADTH                                                          218.80            METERS
DRAFT AFT                                                         23.12            METERS
DRAFT FWD                                                          7.93            METERS
DISPLACEMENT                                                       7.93            METERS
BLOCK COEFFICIENT                                              35640.00            TONNES
MIDSHIP SECTION COEFFICIENT                                        0.88            -----
WATERPLANE COEFFICIENT                                             1.00            -----
RUDDER LATERAL AREA                                                0.91            -----
PROPELLER DIAMETER                                                25.1             SQ. METERS
PROPELLER PITCH/DIAMETER RATIO                                     5.70            METERS
PROPELLER EXPANDED BLADE AREA RATIO                                0.96            -----
SHAFT HORSEPOWER                                                   0.50            -----
*************************************************************  5400.0              KW
                            SHIP SPEED - POWER DATA
SPEED      WAVE       APPEND     BULB BOW    TRANSOM     CORR.     FRICTION     TOTAL      EFFECTIVE
(KNOTS)    RESIST     RESIST     RESIST      RESIST      RESIST    RESIST       RESIST     HORSEPOWER
           (KN)       (KN)       (KN)        (KN)        (KN)      (KN)         (KN)       (KW)
*************************************************************************************************
 10.0   0.528E+01  0.332E+01  0.105E+02  0.000E+00  0.364E+02  0.153E+03  0.253E+03  0.130E+04
 11.0   0.128E+02  0.400E+01  0.121E+02  0.000E+00  0.440E+02  0.183E+03  0.310E+03  0.175E+04
 12.0   0.269E+02  0.473E+01  0.136E+02  0.000E+00  0.524E+02  0.216E+03  0.376E+03  0.232E+04
 13.0   0.507E+02  0.553E+01  0.151E+02  0.000E+00  0.615E+02  0.251E+03  0.457E+03  0.305E+04
 14.0   0.877E+02  0.639E+01  0.165E+02  0.000E+00  0.713E+02  0.288E+03  0.554E+03  0.399E+04
 15.0   0.142E+03  0.731E+01  0.178E+02  0.000E+00  0.819E+02  0.328E+03  0.672E+03  0.519E+04
[redacted]  [redacted]  [redacted]  [redacted]  [redacted]  [redacted]  0.370E+03  [redacted]  0.671E+04
```

```
    17.0    0.314E+03   0.933E+01   0.202E+02   0.000E+00   0.105E+03   0.415E+03   0.985E+03    0.861E+04
    18.0    0.438E+03   0.104E+02   0.213E+02   0.000E+00   0.118E+03   0.462E+03   0.118E+04    0.110E+05
    19.0    0.594E+03   0.116E+02   0.223E+02   0.000E+00   0.131E+03   0.511E+03   0.142E+04    0.139E+05
    20.0    0.777E+03   0.128E+02   0.232E+02   0.000E+00   0.146E+03   0.563E+03   0.169E+04    0.173E+05
WAKE FRACTION =  0.450

THRUST DEDUCTION FRACTION =  0.170

FORM FACTOR OF THE HULL =  0.292

The friction resistance in the above table was
multiplied by (1.+CFORM) to obtain the total
resistance.

**************************************************************************************************************
  TIME      LOCAL       LOCAL        LOCAL          GLOBAL          GLOBAL       YAW ANGLE   ROLL ANGLE   PROPELLER
          X-SPEED     Y-SPEED     SHIP SPEED      X-POSITION      Y-POSITION                               SPEED
 (SECS)    (KNOTS)     (KNOTS)      (KNOTS)        (METERS)        (METERS)      (DEGREES)   (DEGREES)     (RPM)
**************************************************************************************************************
     0.0    10.50        0.00        10.50            0.00            0.00          0.0          0.0        120.0
    10.0    10.84       -0.20        10.84           54.94           -0.21          0.5          0.1        120.3
    20.0    10.95       -0.79        10.97          111.12           -0.99          3.4          0.0        120.6
    30.0    10.94       -1.42        11.03          167.73           -0.80          8.9         -0.1        120.7
    40.0    10.83       -1.94        11.00          224.32            2.55         15.7         -0.2        120.5
    50.0    10.64       -2.30        10.89          280.04           10.66         23.4         -0.2        120.3
    60.0    10.41       -2.54        10.71          333.85           24.41         31.3         -0.3        120.0
    70.0    10.14       -2.68        10.49          384.72           44.03         39.5         -0.3        119.7
    80.0     9.88       -2.76        10.25          431.69           69.30         47.6         -0.3        119.4
    90.0     9.61       -2.80        10.01          474.00           99.68         55.7         -0.3        119.2
   100.0     9.35       -2.81         9.77          511.05          134.48         63.7         -0.3        118.9
   110.0     9.11       -2.80         9.53          542.41          172.91         71.7         -0.3        118.7
   120.0     8.88       -2.79         9.31          567.81          214.12         79.6         -0.3        118.5
   130.0     8.66       -2.77         9.09          587.13          257.27         87.4         -0.3        118.2
   140.0     8.45       -2.75         8.89          600.34          301.56         95.2         -0.3        118.1
   150.0     8.26       -2.73         8.70          607.53          346.21        102.9         -0.3        117.9
   160.0     8.09       -2.71         8.53          608.87          390.47        110.5         -0.2        117.7
```

170.0	7.92	-2.69	8.36	604.62	433.66	118.0	-0.2	117.5
180.0	7.76	-2.66	8.21	595.08	475.17	125.5	-0.2	117.4
190.0	7.62	-2.64	8.06	580.64	514.41	133.0	-0.2	117.3
200.0	7.48	-2.63	7.93	561.71	550.90	140.4	-0.2	117.1
210.0	7.35	-2.61	7.80	538.75	584.18	147.7	-0.2	117.0
220.0	7.24	-2.59	7.68	512.25	613.88	155.0	-0.2	116.9
230.0	7.12	-2.57	7.57	482.72	639.70	162.3	-0.2	116.8
240.0	7.02	-2.56	7.47	450.69	661.37	169.5	-0.2	116.7
250.0	6.92	-2.55	7.38	416.70	678.73	176.7	-0.2	116.6
260.0	6.83	-2.53	7.28	381.30	691.64	183.8	-0.2	116.6
270.0	6.74	-2.52	7.20	345.03	700.05	190.9	-0.2	116.5
280.0	6.66	-2.51	7.12	308.42	703.96	198.0	-0.2	116.4
290.0	6.59	-2.50	7.05	272.01	703.44	205.1	-0.2	116.3
300.0	6.52	-2.49	6.98	236.29	698.59	212.1	-0.2	116.3
310.0	6.45	-2.48	6.91	201.75	689.57	219.1	-0.2	116.2
320.0	6.39	-2.47	6.85	168.85	676.62	226.1	-0.2	116.2
330.0	6.33	-2.46	6.79	138.00	659.98	233.0	-0.2	116.1
340.0	6.27	-2.46	6.73	109.58	639.96	240.0	-0.2	116.1
350.0	6.21	-2.45	6.68	83.96	616.90	246.9	-0.2	116.0
360.0	6.16	-2.44	6.63	61.43	591.17	253.8	-0.2	116.0
370.0	6.11	-2.44	6.58	42.24	563.16	260.7	-0.2	115.9
380.0	6.06	-2.43	6.53	26.61	533.31	267.6	-0.2	115.9
390.0	6.02	-2.43	6.49	14.69	502.04	274.5	-0.2	115.8
400.0	5.97	-2.42	6.44	6.59	469.80	281.4	-0.2	115.8
410.0	5.93	-2.42	6.40	2.36	437.04	288.2	-0.1	115.8
420.0	5.89	-2.42	6.36	2.01	404.22	295.1	-0.1	115.7
430.0	5.85	-2.41	6.33	5.49	371.78	301.9	-0.1	115.7
440.0	5.81	-2.41	6.29	12.71	340.15	308.7	-0.1	115.7
450.0	5.78	-2.41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	5.74	-2.40	6.22	37.72	280.99	322.3	-0.1	115.6

```
  470.0     5.71    -2.40     6.19      55.09    254.22    329.1    -0.1    115.6
  480.0     5.68    -2.40     6.16      75.37    229.78    335.9    -0.1    115.6
  490.0     5.65    -2.39     6.13      98.25    207.98    342.7    -0.1    115.5
  500.0     5.62    -2.39     6.10     123.40    189.08    349.5    -0.1    115.5
  510.0     5.59    -2.39     6.08     150.45    173.30    356.2    -0.1    115.5
  520.0     5.56    -2.39     6.05     179.02    160.83    363.0    -0.1    115.5
  530.0     5.53    -2.38     6.03     208.73    151.81    369.7    -0.1    115.4
END OF TURNING CIRCLE MANOEUVRE

                         RESULTS FROM TIME SIMULATION ANALYSIS
                               TURNING CIRCLE MANOEUVRE
 *************************************************************************************
                  DESCRIPTION                                VALUE              UNITS
--------------------------------------------------------------------------------------
 STEADY TURNING SPEED                                         6.06              KNOTS
 NON-DIMENSIONAL ADVANCE (ADVANCE/LPP)                        2.71              -----
 NON-DIMENSIONAL TRANSFER (TRANSFER/LPP)                      1.26              -----
 NON-DIMENSIONAL TACTICAL DIAMETER (TAC. DIA./LPP)            3.13              -----
 NON-DIMENSIONAL STEADY TURNING DIAMETER (STDY. DIA./LPP)     2.38              -----
 *************************************************************************************

                         RESULTS FROM THE EMPIRICAL ANALYSIS
                               TURNING CIRCLE MANOEUVRE
 *************************************************************************************
                  DESCRIPTION                                VALUE              UNITS
--------------------------------------------------------------------------------------
 STEADY TURNING SPEED                                         3.87              KNOTS
 NON-DIMENSIONAL ADVANCE (ADVANCE/LPP)                        2.87              -----
 NON-DIMENSIONAL TRANSFER (TRANSFER/LPP)                      1.41              -----
 NON-DIMENSIONAL TACTICAL DIAMETER (TAC. DIA./LPP)            2.97              -----
 NON-DIMENSIONAL STEADY TURNING DIAMETER (STDY. DIA./LPP)     2.34              -----
```

```
STANDARD DEVIATION OF (VST/VX1) = 0.185
STANDARD DEVIATION OF (ADV/LPP) = 0.162
STANDARD DEVIATION OF (TR/LPP) = 0.170
STANDARD DEVIATION OF (TACDIA/LPP) = 0.111
STANDARD DEVIATION OF (STDYDIA/LPP) = 0.244

MESSAGES FOR EMPIRICAL TURNING CIRCLE ANALYSIS
______________________________________________
BLOCK COEFFICIENT IS OUTSIDE THE RANGE OF (.56 <= CB <= .87)
RATIO (B/LPP) IS OUTSIDE THE RANGE OF (.11 <= RATIO <= .18)
****************************************************************************************************

                                          CRASH STOP MANOEUVRE
****************************************************************************************************
                    DESCRIPTION                                     VALUE                   UNITS
____________________________________________________________________________________________________
INITIAL SPEED OF SHIP
INITIAL RESISTANCE OF SHIP                                          12.50                   KNOTS
MAXIMUM ASTERN THRUST                                              416.5                     KN
NON-DIMENSIONAL HEAD REACH (REACH/LPP)                             326.8                     KN
                                                                     6.79                   -----
****************************************************************************************************
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AAAAAAAAAA   9999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999   AAAAAAAAAA
AAAAAAAAAA   9999999999999999999999999  Digital Equipment Corporation - VAX/VMS Version V4.6  9999999999999999999999999   AAAAAAAAAA
AAAAAAAAAA   9999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999   AAAAAAAAAA

                                        L       AAA   N   N  TTTTT   OOO   SSSS
                                        L      A   A  N   N    T    O   O S
                                        L      A   A  NN  N    T    O   O S
                                        L      A   A  N N N    T    O   O  SSS
                                        L      AAAAA  N  NN    T    O   O     S
                                        L      A   A  N   N    T    O   O     S
                                        LLLLL  A   A  N   N    T     OOO  SSSS

     FFFFFFFFFF  RRRRRRRR    TTTTTTTTTT           11    5555555555   SSSSSSSS   PPPPPPPP      IIIIII    RRRRRRRR
     FFFFFFFFFF  RRRRRRRR    TTTTTTTTTT           11    5555555555   SSSSSSSS   PPPPPPPP      IIIIII    RRRRRRRR
     FF          RR      RR      TT             1111    55          SS          PP      PP      II      RR      RR
     FF          RR      RR      TT             1111    55          SS          PP      PP      II      RR      RR
     FF          RR      RR      TT               11    55555555    SS          PP      PP      II      RR      RR
     FF          RR      RR      TT               11    55555555    SS          PP      PP      II      RR      RR
     FFFFFFFF    RRRRRRRR        TT               11          55     SSSSSS     PPPPPPPP        II      RRRRRRRR
     FFFFFFFF    RRRRRRRR        TT               11          55     SSSSSS     PPPPPPPP        II      RRRRRRRR
     FF          RR  RR          TT               11            55         SS   PP              II      RR  RR
     FF          RR  RR          TT               11            55         SS   PP              II      RR  RR
     FF          RR    RR        TT               11    55      55         SS   PP              II      RR    RR
     FF          RR    RR        TT               11    55      55         SS   PP              II      RR    RR
     FF          RR      RR      TT             111111    555555    SSSSSSSS    PP            IIIIII    RR      RR
     FF          RR      RR      TT             111111    555555    SSSSSSSS    PP            IIIIII    RR      RR

                                  DDDDDDDD      AAAAAA    TTTTTTTTTT    ;;;;          11
                                  DDDDDDDD      AAAAAA    TTTTTTTTTT    ;;;;          11
                                  DD      DD  AA      AA      TT        ;;;;        1111
                                  DD      DD  AA      AA      TT        ;;;;        1111
                                  DD      DD  AA      AA      TT                      11
                                  DD      DD  AA      AA      TT                      11
                                  DD      DD  AA      AA      TT        ;;;;          11
                                  DD      DD  AAAAAAAAAA      TT        ;;;;          11
                                  DD      DD  AAAAAAAAAA      TT        ;;;;          11
                        ::::      DD      DD  AA      AA      TT        ;;;;          11
                        ::::      DD      DD  AA      AA      TT          ;;          11
                        ::::      DD      DD  AA      AA      TT          ;;          11
                        ::::      DDDDDDDD    AA      AA      TT        ;;          111111
                        ::::      DDDDDDDD    AA      AA      TT        ;;          111111

File _DUA1:[LANTOS]FRT-15SPIR.DAT;1 (818,109,0), last revised on 28-SEP-1988 10:11, is a 1 block sequential file owned by UIC
[QANDM,LANTOS].  The records are variable length with implied (CR) carriage control.  The longest record is 57 bytes.

Job ALQOB-15SPIR (221) queued to SYS$PRINT on 28-SEP-1988 10:14 by user LANTOS, UIC [QANDM,LANTOS], under account QANDM at priority
100, started on printer _TXA3: on 28-SEP-1988 10:26 from queue SYS$PRINT.

AAAAAAAAAA   9999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999   AAAAAAAAAA
AAAAAAAAAA   9999999999999999999999999  Digital Equipment Corporation - VAX/VMS Version V4.6  9999999999999999999999999   AAAAAAAAAA
AAAAAAAAAA   9999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999   AAAAAAAAAA
```

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```
1025.,1.1889E-6,1,9.4,5.712E5
137.,137.,19.9,6.1,4.4,.64,.88,.85,9.246E6
2.33,-11.04,0.,0.,9.77,0.,0.,0.,2.83,0.,0.,0.,0.,0.
0.15,0.,-69.,4.2,0.15,11.4,5.69,1.55,5.19,8.25,0.,11,150.
0.,0,1,0.,0.,8.,3.,1
45.6,1.4
3,4000.,1.,-15.,14,4.05,1.,.8,4,9.888E6,2,-68.,7.3
9.77,2,1,8.,2.,0,5.
```

72

```
LLLLLLLLLL   0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000   LLLLLLLLLL
LLLLLLLLLL   0000000000000000000000000  Digital Equipment Corporation - VAX/VMS Version V4.6  0000000000000000000000000   LLLLLLLLLL
LLLLLLLLLL   0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000   LLLLLLLLLL

                    L       AAA   N   N  TTTTT   OOO   SSSS
                    L      A   A  N   N    T    O   O S
                    L      A   A  NN  N    T    O   O S
                    L      A   A  N N N    T    O   O  SSS
                    L      AAAAA  N  NN    T    O   O     S
                    L      A   A  N   N    T    O   O     S
                    LLLLL  A   A  N   N    T     OOO  SSSS

  SSSSSSSS    IIIIII    MM      MM  UU      UU    LL
  SSSSSSSS    IIIIII    MM      MM  UU      UU    LL
SS              II      MMMM  MMMM  UU      UU    LL
SS              II      MMMM  MMMM  UU      UU    LL
SS              II      MM  MM  MM  UU      UU    LL
SS              II      MM  MM  MM  UU      UU    LL
  SSSSSS        II      MM      MM  UU      UU    LL
  SSSSSS        II      MM      MM  UU      UU    LL
        SS      II      MM      MM  UU      UU    LL
        SS      II      MM      MM  UU      UU    LL
        SS      II      MM      MM  UU      UU    LL
        SS      II      MM      MM  UU      UU    LL
SSSSSSSS      IIIIII    MM      MM  UUUUUUUUUU    LLLLLLLLLL
SSSSSSSS      IIIIII    MM      MM  UUUUUUUUUU    LLLLLLLLLL

  OOOOOO    UU      UU  TTTTTTTTTT      ;;;;        11          11
  OOOOOO    UU      UU  TTTTTTTTTT      ;;;;        11          11
OO      OO  UU      UU      TT          ;;;;      1111        1111
OO      OO  UU      UU      TT          ;;;;      1111        1111
OO      OO  UU      UU      TT                      11          11
OO      OO  UU      UU      TT                      11          11
OO      OO  UU      UU      TT          ;;;;        11          11
OO      OO  UU      UU      TT          ;;;;        11          11
OO      OO  UU      UU      TT          ;;;;        11          11
OO      OO  UU      UU      TT          ;;;;        11          11
OO      OO  UU      UU      TT            ;;        11          11
OO      OO  UU      UU      TT            ;;        11          11
  OOOOOO    UUUUUUUUUU      TT          ;;        111111      111111
  OOOOOO    UUUUUUUUUU      TT          ;;        111111      111111

File _DUA1:[LANTOS]SIMUL.OUT;11 (515,5891,0), last revised on 28-SEP-1988 10:45, is a 64 block sequential file owned by UIC
[QANDM,LANTOS].  The records are variable length with FORTRAN (FTN) carriage control.  The longest record is 116 bytes.

Job SIMUL (226) queued to SYS$PRINT on 28-SEP-1988 10:52 by user LANTOS, UIC [QANDM,LANTOS], under account QANDM at priority 100,
started on printer _TXA3: on 28-SEP-1988 10:57 from queue SYS$PRINT.

LLLLLLLLLL   0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000   LLLLLLLLLL
LLLLLLLLLL   0000000000000000000000000  Digital Equipment Corporation - VAX/VMS Version V4.6  0000000000000000000000000   LLLLLLLLLL
LLLLLLLLLL   0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000   LLLLLLLLLL
```

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```
                                    INPUT DATA
                                 SPIRAL MANOEUVRE
***********************************************************************************************
                 DESCRIPTION                                   VALUE                 UNITS
-----------------------------------------------------------------------------------------------
LENGTH BETWEEN PERPENDICULARS
LENGTH ON WATERLINE                                           137.00                METERS
BREADTH                                                       137.00                METERS
DRAFT AFT                                                      19.90                METERS
DRAFT FWD                                                       6.10                METERS
DISPLACEMENT                                                    4.40                METERS
BLOCK COEFFICIENT                                            9246.00                TONNES
MIDSHIP SECTION COEFFICIENT                                     0.64                -----
WATERPLANE COEFFICIENT                                          0.88                -----
RUDDER LATERAL AREA                                             0.85                -----
PROPELLER DIAMETER                                             11.4                 SQ. METERS
PROPELLER PITCH/DIAMETER RATIO                                  4.05                METERS
PROPELLER EXPANDED BLADE AREA RATIO                             1.00                -----
SHAFT HORSEPOWER                                                0.80                -----
                                                             9888.0                 KW
***********************************************************************************************
                              SHIP SPEED - POWER DATA
 SPEED      WAVE        APPEND      BULB BOW     TRANSOM      CORR.       FRICTION     TOTAL       EFFECTIVE
(KNOTS)    RESIST       RESIST       RESIST       RESIST      RESIST       RESIST      RESIST      HORSEPOWER
            (KN)         (KN)         (KN)         (KN)        (KN)         (KN)        (KN)          (KW)
***********************************************************************************************
 14.0    0.389E+02    0.266E+01    0.364E+02    0.000E+00    0.381E+02    0.129E+03    0.285E+03    0.205E+04
 15.0    0.624E+02    0.303E+01    0.381E+02    0.000E+00    0.437E+02    0.147E+03    0.340E+03    0.262E+04
 16.0    0.953E+02    0.342E+01    0.395E+02    0.000E+00    0.497E+02    0.166E+03    0.405E+03    0.334E+04
 17.0    0.139E+03    0.383E+01    0.408E+02    0.000E+00    0.562E+02    0.186E+03    0.484E+03    0.423E+04
 18.0    0.188E+03    0.426E+01    0.420E+02    0.000E+00    0.630E+02    0.207E+03    0.568E+03    0.526E+04
 19.0    0.249E+03    0.471E+01    0.431E+02    0.000E+00    0.701E+02    0.22[illegible]E+03    0.647E+03    0.652E+04
 2[illegible]    0.[illegible]E+03    0.51[illegible]E+01    0.440E+02    0.000E+00    0.777E+02    0.252E+03    0.803E+03    0.827E+04
```

```
  21.0    0.478E+03   0.569E+01   0.448E+02   0.000E+00   0.857E+02   0.276E+03   0.977E+03    0.106E+05
  22.0    0.608E+03   0.621E+01   0.456E+02   0.000E+00   0.940E+02   0.301E+03   0.115E+04    0.130E+05
  23.0    0.696E+03   0.675E+01   0.463E+02   0.000E+00   0.103E+03   0.328E+03   0.128E+04    0.152E+05
  24.0    0.746E+03   0.731E+01   0.469E+02   0.000E+00   0.112E+03   0.355E+03   0.138E+04    0.170E+05
 WAKE FRACTION =  0.150
 THRUST DEDUCTION FRACTION =  0.195
 FORM FACTOR OF THE HULL =  0.312
 The friction resistance in the above table was
 multiplied by (1.+CFORM) to obtain the total
 resistance.
 ***************************************************************************************************************
  TIME       LOCAL        LOCAL        LOCAL          GLOBAL         GLOBAL        YAW ANGLE   ROLL ANGLE   PROPELLER
            X-SPEED      Y-SPEED     SHIP SPEED     X-POSITION     Y-POSITION                               SPEED
  (SECS)    (KNOTS)      (KNOTS)      (KNOTS)        (METERS)       (METERS)      (DEGREES)    (DEGREES)     (RPM)
 ***************************************************************************************************************
    0.0      18.99        0.00        18.99            0.00           0.00           0.0          0.0       169.8
   10.0      18.60        1.02        18.63           96.83           0.27          -3.8          1.2       168.4
   20.0      18.02        1.98        18.13          191.20          -5.81         -14.0          2.6       166.1
   30.0      17.27        2.47        17.45          280.14         -26.86         -27.6          3.3       163.1
   40.0      16.50        2.64        16.71          358.66         -65.74         -42.6          3.5       160.0
   50.0      15.79        2.65        16.01          422.20        -120.52         -57.7          3.4       157.2
   60.0      15.19        2.60        15.42          467.88        -186.91         -72.5          3.2       154.9
   70.0      14.70        2.54        14.91          494.51        -259.98         -87.0          3.0       152.9
   80.0      14.29        2.48        14.50          502.21        -335.02        -101.0          2.9       151.3
   90.0      13.95        2.42        14.16          492.02        -407.83        -114.6          2.7       150.0
  100.0      13.68        2.38        13.88          465.70        -474.79        -128.0          2.6       149.0
  110.0      13.45        2.34        13.65          425.49        -532.88        -141.1          2.5       148.1
  120.0      13.26        2.31        13.46          374.03        -579.72        -154.0          2.4       147.4
  130.0      13.11        2.28        13.31          314.23        -613.53        -166.7          2.4       146.8
 RUDDER ANGLE =  -10.00000

  140.0      12.98        2.26        13.17          249.18        -633.20        -179.3          2.3       146.3
```

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```
     150.0     12.98      2.08      13.15       181.82     -638.10     -191.0      2.1      146.3
     160.0     13.04      1.98      13.19       114.79     -629.08     -201.9      2.0      146.5
     170.0     13.12      1.94      13.26        50.42     -607.32     -212.4      2.0      146.8
     180.0     13.20      1.92      13.34        -9.16     -573.83     -222.9      2.0      147.1
     190.0     13.28      1.91      13.42       -61.94     -529.81     -233.2      2.0      147.3
     200.0     13.35      1.91      13.49      -106.12     -476.67     -243.6      2.0      147.6
     210.0     13.41      1.91      13.55      -140.12     -416.12     -254.0      2.0      147.8
     220.0     13.46      1.92      13.60      -162.69     -350.14     -264.4      2.0      148.0
     230.0     13.51      1.92      13.65      -172.95     -280.90     -274.9      2.0      148.2
     240.0     13.55      1.93      13.69      -170.42     -210.73     -285.4      2.0      148.4
     250.0     13.58      1.93      13.72      -155.10     -142.01     -295.9      2.0      148.5
     260.0     13.61      1.94      13.75      -127.40      -77.11     -306.5      2.0      148.6
     270.0     13.64      1.94      13.78       -88.20      -18.26     -317.1      2.0      148.7
 RUDDER ANGLE =   -5.000000

     280.0     13.74      1.77      13.85       -38.62       32.45     -326.9      1.8      149.0
     290.0     13.89      1.65      13.98        19.45       74.16     -335.7      1.7      149.5
     300.0     14.05      1.58      14.14        84.01      106.63     -344.0      1.7      150.2
     310.0     14.22      1.54      14.30       153.44      129.47     -352.1      1.7      150.8
     320.0     14.37      1.52      14.45       226.21      142.29     -360.1      1.7      151.4
     330.0     14.51      1.52      14.59       300.81      144.78     -368.1      1.7      151.9
     340.0     14.64      1.52      14.72       375.70      136.74     -376.1      1.7      152.4
     350.0     14.75      1.52      14.83       449.35      118.18     -384.1      1.7      152.9
     360.0     14.85      1.53      14.93       520.17       89.30     -392.1      1.7      153.2
     370.0     14.94      1.54      15.02       586.66       50.52     -400.2      1.7      153.6
     380.0     15.02      1.55      15.09       647.35        2.49     -408.3      1.7      153.9
     390.0     15.08      1.55      15.16       700.87      -53.92     -416.5      1.8      154.1
     400.0     15.14      1.56      15.22       746.01     -117.64     -424.7      1.8      154.4
 RUDDER ANGLE =   0.0000000E+00
[redacted]
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   420.0    15.33    1.24    15.38     807.28    -261.90   -439.2    1.6    155.1
   430.0    15.50    1.07    15.54     824.26    -339.55   -444.6    1.3    155.7
   440.0    15.68    0.95    15.70     833.69    -419.32   -449.2    1.1    156.4
   450.0    15.85    0.85    15.87     836.38    -500.48   -453.4    1.0    157.1
   460.0    16.02    0.78    16.04     832.95    -582.49   -457.1    0.9    157.7
   470.0    16.18    0.71    16.20     823.92    -664.91   -460.6    0.8    158.4
   480.0    16.34    0.66    16.35     809.71    -747.41   -463.8    0.8    159.0
   490.0    16.47    0.62    16.49     790.67    -829.69   -466.7    0.7    159.5
   500.0    16.60    0.59    16.61     767.13    -911.51   -469.5    0.7    160.1
   510.0    16.72    0.55    16.73     739.36    -992.65   -472.2    0.7    160.5
   520.0    16.83    0.53    16.84     707.62   -1072.94   -474.7    0.6    161.0
   530.0    16.93    0.50    16.93     672.14   -1152.23   -477.0    0.6    161.4
   540.0    17.01    0.48    17.02     633.13   -1230.37   -479.3    0.6    161.7
   550.0    17.09    0.47    17.10     590.80   -1307.25   -481.5    0.6    162.0
   560.0    17.17    0.45    17.17     545.31   -1382.77   -483.6    0.5    162.3
   570.0    17.23    0.44    17.24     496.84   -1456.82   -485.7    0.5    162.6
   580.0    17.29    0.42    17.30     445.55   -1529.35   -487.7    0.5    162.8
   590.0    17.34    0.41    17.35     391.59   -1600.26   -489.6    0.5    163.1
   600.0    17.39    0.40    17.40     335.09   -1669.50   -491.5    0.5    163.2
   610.0    17.43    0.39    17.44     276.18   -1737.02   -493.3    0.5    163.4
   620.0    17.47    0.38    17.48     215.00   -1802.77   -495.1    0.5    163.6
   630.0    17.51    0.37    17.51     151.66   -1866.70   -496.8    0.4    163.7
   640.0    17.54    0.37    17.54      86.27   -1928.78   -498.5    0.4    163.8
   650.0    17.57    0.36    17.57      18.94   -1988.97   -500.2    0.4    164.0
   660.0    17.59    0.35    17.60     -50.23   -2047.26   -501.9    0.4    164.1
 RUDDER ANGLE =    5.000000

   670.0    17.61    0.32    17.61    -121.14   -2103.60   -503.4    0.5    164.2
   680.0    17.62   -0.10    17.62    -193.66   -2157.93   -503.2    0.1    164.2
   690.0    17.60   -0.57    17.61    -266.07   -2212.41   -500.4   -0.4    164.1
   700.0    17.54   -0.97    17.57    -336.00   -2269.84   -495.5   -1.0    163.9
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   710.0     17.42     -1.27     17.47      -400.87     -2332.36     -489.0      -1.5
   720.0     17.26     -1.47     17.32      -458.16     -2401.06     -481.4      -1.8      163.4
   730.0     17.08     -1.59     17.15      -505.63     -2475.87     -473.1      -2.0      162.8
   740.0     16.89     -1.66     16.97      -541.55     -2555.85     -464.3      -2.1      162.1
   750.0     16.70     -1.70     16.79      -564.77     -2639.43     -455.3      -2.1      161.3
   760.0     16.54     -1.71     16.62      -574.66     -2724.72     -446.2      -2.1      160.6
   770.0     16.39     -1.71     16.47      -571.09     -2809.68     -437.1      -2.1      159.9
   780.0     16.25     -1.71     16.34      -554.35     -2892.32     -428.0      -2.1      159.3
   790.0     16.14     -1.70     16.23      -525.07     -2970.70     -419.0      -2.1      158.8
   800.0     16.04     -1.69     16.12      -484.15     -3043.05     -410.0      -2.1      158.3
   810.0     15.95     -1.68     16.04      -432.77     -3107.77     -401.1      -2.0      157.9
   820.0     15.87     -1.68     15.96      -372.29     -3163.47     -392.2      -2.0      157.6
   830.0     15.81     -1.67     15.90      -304.24     -3208.99     -383.3      -2.0      157.3
   840.0     15.76     -1.66     15.84      -230.28     -3243.39     -374.5      -2.0      157.0
RUDDER ANGLE =    10.00000                                                                 156.8

   850.0     15.65     -1.81     15.76      -152.27     -3266.12     -365.3      -1.9      156.5
   860.0     15.46     -1.99     15.59       -72.32     -3275.99     -354.6      -2.3      155.7
   870.0     15.24     -2.08     15.38         7.08     -3271.16     -343.2      -2.5      154.9
   880.0     15.03     -2.11     15.17        82.99     -3251.27     -331.6      -2.5      154.1
   890.0     14.83     -2.12     14.98       152.49     -3217.14     -319.9      -2.5      153.3
   900.0     14.66     -2.11     14.81       212.99     -3170.35     -308.3      -2.4      152.6
   910.0     14.51     -2.10     14.66       262.40     -3113.05     -296.8      -2.4      152.0
   920.0     14.38     -2.08     14.53       299.09     -3047.69     -285.4      -2.3      151.5
   930.0     14.27     -2.07     14.42       321.97     -2976.96     -274.0      -2.3      151.1
   940.0     14.18     -2.06     14.33       330.49     -2903.63     -262.8      -2.3      150.8
   950.0     14.10     -2.04     14.25       324.61     -2830.47     -251.6      -2.3      150.5
   960.0     14.04     -2.03     14.19       304.76     -2760.19     -240.4      -2.2      150.2
   970.0     13.98     -2.03     14.13       271.88     -2695.33     -229.3      -2.2      150.0
RUDDER ANGLE =    15.00000
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    980.0    13.87    -2.14    14.03     227.45   -2638.19   -217.9    -2.1    149.7
    990.0    13.67    -2.26    13.85     173.25   -2591.37   -205.4    -2.4    148.9
   1000.0    13.46    -2.30    13.66     111.21   -2557.64   -192.5    -2.5    148.1
   1010.0    13.27    -2.31    13.47      44.24   -2538.65   -179.5    -2.5    147.4
   1020.0    13.10    -2.30    13.30     -24.35   -2535.03   -166.7    -2.4    146.8
   1030.0    12.95    -2.28    13.15     -91.26   -2546.52   -153.9    -2.4    146.2
   1040.0    12.83    -2.27    13.03    -153.36   -2572.17   -141.2    -2.3    145.8
   1050.0    12.73    -2.25    12.92    -207.89   -2610.43   -128.6    -2.3    145.4
   1060.0    12.64    -2.24    12.84    -252.50   -2659.24   -116.1    -2.2    145.1
   1070.0    12.57    -2.23    12.76    -285.32   -2716.17   -103.7    -2.2    144.8
   1080.0    12.51    -2.22    12.70    -305.06   -2778.49    -91.3    -2.2    144.6
   1090.0    12.45    -2.21    12.65    -311.00   -2843.29    -79.0    -2.2    144.4
RUDDER ANGLE =   10.00000

   1100.0    12.43    -2.16    12.62    -303.02   -2907.64    -66.8    -2.3    144.2
   1110.0    12.52    -2.02    12.68    -281.46   -2968.86    -55.6    -2.1    144.5
   1120.0    12.64    -1.94    12.79    -247.97   -3025.02    -45.0    -2.0    145.0
   1130.0    12.77    -1.91    12.91    -204.18   -3074.39    -34.7    -1.9    145.4
   1140.0    12.89    -1.90    13.02    -151.64   -3115.33    -24.4    -1.9    145.9
   1150.0    13.00    -1.90    13.13     -92.05   -3146.40    -14.0    -1.9    146.3
   1160.0    13.09    -1.90    13.23     -27.34   -3166.38     -3.7    -1.9    146.6
   1170.0    13.18    -1.91    13.32      40.38   -3174.40      6.7    -1.9    147.0
   1180.0    13.25    -1.92    13.39     108.83   -3170.00     17.2    -2.0    147.2
   1190.0    13.31    -1.93    13.45     175.69   -3153.13     27.6    -2.0    147.5
   1200.0    13.37    -1.93    13.51     238.62   -3124.21     38.2    -2.0    147.7
   1210.0    13.42    -1.94    13.55     295.39   -3084.10     48.8    -2.0    147.9
   1220.0    13.45    -1.95    13.59     343.98   -3034.07     59.4    -2.0    148.0
RUDDER ANGLE =    5.000000

   1230.0    13.52    -1.87    13.64     382.56   -2975.74     69.8    -2.3    148.2
   1240.0    13.66    -1.71    13.77     409.98   -2910.91     79.1    -2.0    148.7
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   1250.0    13.84    -1.61    13.93      426.60    -2841.72     87.6     -1.8     149.4
   1260.0    14.01    -1.56    14.10      432.61    -2769.94     95.8     -1.7     150.0
   1270.0    14.18    -1.54    14.27      428.07    -2697.18    103.9     -1.6     150.7
   1280.0    14.34    -1.53    14.42      413.06    -2625.00    111.9     -1.6     151.3
   1290.0    14.48    -1.53    14.56      387.77    -2554.93    119.9     -1.7     151.8
   1300.0    14.61    -1.53    14.69      352.57    -2488.51    127.9     -1.7     152.3
   1310.0    14.72    -1.54    14.80      308.02    -2427.20    136.0     -1.7     152.7
   1320.0    14.82    -1.55    14.90      254.87    -2372.42    144.2     -1.7     153.1
   1330.0    14.90    -1.55    14.98      194.12    -2325.45    152.3     -1.7     153.4
   1340.0    14.98    -1.56    15.06      126.93    -2287.42    160.6     -1.8     153.7
   1350.0    15.04    -1.57    15.12       54.65    -2259.29    168.8     -1.8     154.0
 RUDDER ANGLE =  0.0000000E+00

   1360.0    15.10    -1.38    15.18      -21.24    -2241.79    177.1     -1.8     154.2
   1370.0    15.21    -1.34    15.26      -99.19    -2235.53    184.3     -1.5     154.6
   1380.0    15.37    -1.14    15.41     -177.94    -2239.23    190.1     -1.3     155.2
   1390.0    15.55    -1.00    15.58     -256.70    -2251.29    195.1     -1.2     155.9
   1400.0    15.73    -0.89    15.76     -334.93    -2270.56    199.4     -1.1     156.6
   1410.0    15.91    -0.81    15.93     -412.28    -2296.21    203.3     -0.9     157.3
   1420.0    16.08    -0.74    16.10     -488.44    -2327.56    206.9     -0.9     158.0
   1430.0    16.24    -0.68    16.25     -563.20    -2364.07    210.2     -0.8     158.6
   1440.0    16.39    -0.64    16.40     -636.37    -2405.29    213.2     -0.7     159.2
   1450.0    16.52    -0.60    16.53     -707.81    -2450.81    216.1     -0.7     159.7
   1460.0    16.65    -0.57    16.66     -777.39    -2500.29    218.8     -0.7     160.2
   1470.0    16.76    -0.54    16.77     -845.00    -2553.42    221.3     -0.6     160.7
   1480.0    16.87    -0.51    16.88     -910.57    -2609.91    223.7     -0.6     161.1
   1490.0    16.96    -0.49    16.97     -974.01    -2669.52    226.1     -0.6     161.5
   1500.0    17.05    -0.47    17.05    -1035.27    -2732.01    228.3     -0.6     161.8
   1510.0    17.12    -0.46    17.13    -1094.31    -2797.17    230.5     -0.5     162.2
[illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]
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 1530.0    17.26    -0.43    17.26    -1205.53    -2934.75    234.5    -0.5    162.7
 1540.0    17.31    -0.42    17.32    -1257.66    -3006.82    236.5    -0.5    162.9
 1550.0    17.36    -0.40    17.37    -1307.45    -3080.85    238.4    -0.5    163.1
 1560.0    17.41    -0.39    17.41    -1354.88    -3156.72    240.2    -0.5    163.3
 1570.0    17.45    -0.38    17.46    -1399.93    -3234.27    242.0    -0.5    163.5
 1580.0    17.49    -0.38    17.49    -1442.60    -3313.39    243.8    -0.4    163.6
 1590.0    17.52    -0.37    17.53    -1482.89    -3393.94    245.5    -0.4    163.8
 1600.0    17.55    -0.36    17.55    -1520.81    -3475.82    247.2    -0.4    163.9
 1610.0    17.58    -0.35    17.58    -1556.34    -3558.92    248.8    -0.4    164.0
 1620.0    17.60    -0.35    17.61    -1589.50    -3643.13    250.5    -0.4    164.1
RUDDER ANGLE =  -5.000000

 1630.0    17.61    -0.10    17.61    -1620.16    -3728.38    251.3    -0.3    164.2
 1640.0    17.61     0.35    17.62    -1649.61    -3814.07    249.6     0.2    164.2
 1650.0    17.58     0.77    17.59    -1681.09    -3899.00    245.7     0.8    164.0
 1660.0    17.49     1.11    17.53    -1717.63    -3981.62    240.1     1.3    163.7
 1670.0    17.36     1.35    17.41    -1761.48    -4060.03    233.1     1.6    163.2
 1680.0    17.19     1.51    17.25    -1813.80    -4132.16    225.3     1.9    162.5
 1690.0    17.01     1.61    17.08    -1874.74    -4195.99    216.8     2.0    161.8
 1700.0    16.83     1.66    16.91    -1943.55    -4249.78    208.1     2.1    161.1
 1710.0    16.65     1.69    16.74    -2018.91    -4292.15    199.1     2.1    160.4
 1720.0    16.50     1.69    16.58    -2099.12    -4322.11    190.2     2.1    159.8
 1730.0    16.36     1.69    16.44    -2182.26    -4339.12    181.2     2.1    159.2
 1740.0    16.23     1.69    16.32    -2266.36    -4342.96    172.2     2.1    158.7
 1750.0    16.13     1.68    16.21    -2349.46    -4333.77    163.3     2.1    158.3
 1760.0    16.03     1.67    16.12    -2429.64    -4311.98    154.4     2.0    157.9
 1770.0    15.96     1.67    16.04    -2505.11    -4278.31    145.6     2.0    157.6
 1780.0    15.89     1.66    15.97    -2574.22    -4233.69    136.8     2.0    157.3
 1790.0    15.83     1.65    15.91    -2635.49    -4179.28    128.1     2.0    157.1
RUDDER ANGLE =  -10.00000
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     1800.0    15.78     1.64    15.86     -2687.62    -4116.42    119.4     2.0     156.9
     1810.0    15.63     1.87    15.74     -2729.53    -4046.81    109.6     2.2     156.4
     1820.0    15.43     2.01    15.56     -2758.88    -3971.94     98.7     2.4     155.6
     1830.0    15.22     2.07    15.36     -2773.64    -3893.91     87.4     2.4     154.8
     1840.0    15.01     2.10    15.16     -2772.98    -3815.54     75.9     2.4     154.0
     1850.0    14.83     2.10    14.98     -2757.07    -3739.81     64.4     2.4     153.3
     1860.0    14.67     2.09    14.82     -2726.84    -3669.53     52.9     2.4     152.7
     1870.0    14.53     2.07    14.68     -2683.77    -3607.21     41.6     2.4     152.1
     1880.0    14.42     2.06    14.56     -2629.79    -3555.01     30.3     2.3     151.7
     1890.0    14.32     2.04    14.46     -2567.15    -3514.62     19.1     2.3     151.3
     1900.0    14.23     2.03    14.38     -2498.32    -3487.28      8.0     2.3     151.0
     1910.0    14.16     2.02    14.31     -2425.90    -3473.77     -3.1     2.2     150.7
     1920.0    14.10     2.01    14.25     -2352.58    -3474.36    -14.1     2.2     150.5
 RUDDER ANGLE =  -15.00000

     1930.0    14.05     2.01    14.19     -2280.99    -3488.85    -25.0     2.2     150.3
     1940.0    13.89     2.17    14.06     -2213.82    -3516.36    -36.8     2.4     149.7
     1950.0    13.69     2.26    13.87     -2154.29    -3556.34    -49.4     2.4     149.0
     1960.0    13.49     2.29    13.68     -2105.36    -3607.41    -62.1     2.4     148.2
     1970.0    13.31     2.29    13.50     -2069.26    -3667.12    -74.9     2.4     147.6
     1980.0    13.15     2.27    13.35     -2047.38    -3732.48    -87.6     2.4     147.0
     1990.0    13.02     2.26    13.22     -2040.37    -3800.30   -100.2     2.3     146.5
     2000.0    12.91     2.24    13.10     -2048.18    -3867.40   -112.7     2.3     146.1
     2010.0    12.81     2.23    13.01     -2070.08    -3930.74   -125.1     2.3     145.7
     2020.0    12.74     2.21    12.93     -2104.81    -3987.54   -137.5     2.2     145.4
     2030.0    12.67     2.20    12.86     -2150.59    -4035.36   -149.7     2.2     145.2
     2040.0    12.61     2.19    12.80     -2205.20    -4072.22   -162.0     2.2     145.0
     2050.0    12.57     2.19    12.76     -2266.11    -4096.62   -174.1     2.2     144.8
 RUDDER ANGLE =  -20.00000
 EN  SPI  TEST
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                              RESULTS FROM TIME SIMULATION ANALYSIS
                                       SPIRAL MANOEUVRE
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                    DESCRIPTION                                      VALUE                          UNITS
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THE RESULTS FOR THE SPIRAL TEST ARE SUMMARIZED BELOW.  THEY ARE THE
CONSTANT RATES OF TURN AT EACH RUDDER ANGLE, STARTING WITH THE INITIAL
ANGLE, AND SUBSEQUENTLY CHANGING BY "DELTANG".
THE INITIAL RUDDER ANGLE IS
                                                                  -15.00                         DEGREES
THE CHANGE OF RUDDER ANGLE IS                                       5.00                         DEGREES
  THE ANGLE IS = -15.0
THE CONSTANT YAW RATE IS
                                                                 -0. 125E+01                     DEG. /SEC.
  THE ANGLE IS = -10.0
THE CONSTANT YAW RATE IS
                                                                 -0. 106E+01                     DEG. /SEC.
  THE ANGLE IS =  -5.0
THE CONSTANT YAW RATE IS
                                                                 -0. 824E+00                     DEG. /SEC.
  THE ANGLE IS =   0.0
THE CONSTANT YAW RATE IS
                                                                 -0. 160E+00                     DEG. /SEC.
  THE ANGLE IS =   5.0
THE CONSTANT YAW RATE IS
                                                                  0. 877E+00                     DEG. /SEC.
  THE ANGLE IS =  10.0
THE CONSTANT YAW RATE IS
                                                                  0. 111E+01                     DEG. /SEC.
  THE ANGLE IS =  15.0
THE CONSTANT YAW RATE IS
                                                                  0. 123E+01                     DEG. /SEC.
  THE ANGLE IS =  10.0
THE CONSTANT YAW RATE IS
                                                                  0. 106E+01                     DEG. /SEC.
  THE ANGLE IS =   5.0
THE CONSTANT YAW RATE IS
                                                                  0. 832E+00                     DEG. /SEC.
  THE ANGLE IS =   0.0
THE CONSTANT YAW RATE IS
                                                                  0. 160E+00                     DEG. /SEC.
  THE ANGLE IS =  -5.0
THE CONSTANT YAW RATE IS
                                                                 -0. 868E+00                     DEG. /SEC.
  THE ANGLE IS = -10.0
THE CONSTANT YAW RATE IS
                                                                 -0. 109E+01                     DEG. /SEC.
  THE ANGLE IS = -15.0
THE CONSTANT YAW RATE IS
                                                                 -0. 121E+01                     DEG. /SEC.
```

03

```
********************************************************************************

                       RESULTS FROM THE EMPIRICAL ANALYSIS

                              CRASH STOP MANOEUVRE
********************************************************************************
              DESCRIPTION                         VALUE               UNITS
________________________________________________________________________________
INITIAL SPEED OF SHIP                             18.99               KNOTS
INITIAL RESISTANCE OF SHIP                       666.5                 KN
MAXIMUM ASTERN THRUST                            571.2                 KN
NON-DIMENSIONAL HEAD REACH (REACH/LPP)             4.48               -----
********************************************************************************
```

```
BBBBBBBBBB     99999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999    BBBBBBBBBB
BBBBBBBBBB     999999999999999999999999  Digital Equipment Corporation - VAX/VMS Version V4.6  999999999999999999999999    BBBBBBBBBB
BBBBBBBBBB     99999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999    BBBBBBBBBB

                                              L      AAA  N   N TTTTT  OOO   SSSS
                                              L     A   A N   N   T   O   O S
                                              L     A   A NN  N   T   O   O S
                                              L     A   A N N N   T   O   O  SSS
                                              L     AAAAA N  NN   T   O   O     S
                                              L     A   A N   N   T   O   O     S
                                              LLLLL A   A N   N   T    OOO  SSSS

             FFFFFFFFFF  RRRRRRRR    TTTTTTTTTT                333333    5555555555    CCCCCCCC    IIIIII    RRRRRRRR
             FFFFFFFFFF  RRRRRRRR    TTTTTTTTTT                333333    5555555555    CCCCCCCC    IIIIII    RRRRRRRR
             FF          RR      RR      TT                  33      33  55          CC              II      RR      RR
             FF          RR      RR      TT                  33      33  55          CC              II      RR      RR
             FF          RR      RR      TT                          33  555555      CC              II      RR      RR
             FF          RR      RR      TT                          33  555555      CC              II      RR      RR
             FFFFFFFF    RRRRRRRR        TT                        33          55    CC              II      RRRRRRRR
             FFFFFFFF    RRRRRRRR        TT                        33          55    CC              II      RRRRRRRR
             FF          RR  RR          TT                          33          55  CC              II      RR  RR
             FF          RR  RR          TT                          33          55  CC              II      RR  RR
             FF          RR    RR        TT                  33      33  55      55  CC              II      RR    RR
             FF          RR    RR        TT                  33      33  55      55  CC              II      RR    RR
             FF          RR      RR      TT                    333333      555555      CCCCCCCC    IIIIII    RR      RR
             FF          RR      RR      TT                    333333      555555      CCCCCCCC    IIIIII    RR      RR

                                           DDDDDDDD      AAAAAA    TTTTTTTTTT      ;;;;        11
                                           DDDDDDDD      AAAAAA    TTTTTTTTTT      ;;;;        11
                                           DD      DD  AA      AA      TT          ;;;;      1111
                                           DD      DD  AA      AA      TT          ;;;;      1111
                                           DD      DD  AA      AA      TT                      11
                                           DD      DD  AA      AA      TT                      11
                                           DD      DD  AA      AA      TT          ;;;;        11
                                           DD      DD  AA      AA      TT          ;;;;        11
                                           DD      DD  AAAAAAAAAA      TT          ;;;;        11
                                           DD      DD  AAAAAAAAAA      TT          ;;;;        11
                                    ....   DD      DD  AA      AA      TT            ;;        11
                                    ....   DD      DD  AA      AA      TT            ;;        11
                                    ....   DDDDDDDD    AA      AA      TT          ;;        111111
                                    ....   DDDDDDDD    AA      AA      TT          ;;        111111

File _DUA1:[LANTOS]FRT-35CIR.DAT;1 (974,77,0), last revised on 28-SEP-1988 10:11, is a 1 block sequential file owned by UIC
[QANDM,LANTOS].  The records are variable length with implied (CR) carriage control.  The longest record is 57 bytes.

Job ALGOB-158PIR (221) queued to SYS$PRINT on 28-SEP-1988 10:14 by user LANTOS, UIC [QANDM,LANTOS], under account QANDM at priority
100, started on printer _TXA3: on 28-SEP-1988 10:26 from queue SYS$PRINT.

BBBBBBBBBB     99999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999    BBBBBBBBBB
BBBBBBBBBB     999999999999999999999999  Digital Equipment Corporation - VAX/VMS Version V4.6  999999999999999999999999    BBBBBBBBBB
BBBBBBBBBB     99999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999    BBBBBBBBBB
```

```
1025. , 1. 1889E-6, 1, 9. 4, 5. 712E5
137. , 137. , 19. 9, 6. 1, 4. 4, . 64, . 88, . 85, 9. 246E6
2. 33, -11. 04, 0. , 0. , 9. 77, 0. , 0. , 0. , 2. 83, 0. , 0. , 0. , 0. , 0.
0. 15, 0. , -69. , 4. 2, 0. 15, 11. 4, 5. 69, 1. 55, 5. 19, 8. 25, 0. , 11, 150.
0. , 0, 1, 0. , 0. , 8. , 3. , 1
45. 6, 1. 4
1, 4000. , 1. , -35. , 14, 4. 05, 1. , . 8, 4, 9. 888E6, 2, -68. , 7. 3
9. 77, 2, 1, 8. , 2. , 0, 5.
```

```
KKKKKKKKKK   0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000   KKKKKKKKKK
KKKKKKKKKK   0000000000000000000000000  Digital Equipment Corporation - VAX/VMS Version V4.6  00000000000000000000000000   KKKKKKKKKK
KKKKKKKKKK   0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000   KKKKKKKKKK

                              L       AAA   N   N  TTTTT   OOO   SSSS
                              L      A   A  NN  N    T    O   O S
                              L      A   A  N N N    T    O   O S
                              L      A   A  N  NN    T    O   O  SSS
                              L      AAAAA  N   N    T    O   O     S
                              L      A   A  N   N    T    O   O     S
                              LLLLL  A   A  N   N    T     OOO  SSSS

                           SSSSSSSS    IIIIII    MM      MM  UU      UU  LL
                           SSSSSSSS    IIIIII    MM      MM  UU      UU  LL
                         SS              II      MMMM  MMMM  UU      UU  LL
                         SS              II      MMMM  MMMM  UU      UU  LL
                         SS              II      MM  MM  MM  UU      UU  LL
                         SS              II      MM  MM  MM  UU      UU  LL
                           SSSSSS        II      MM      MM  UU      UU  LL
                           SSSSSS        II      MM      MM  UU      UU  LL
                                 SS      II      MM      MM  UU      UU  LL
                                 SS      II      MM      MM  UU      UU  LL
                                 SS      II      MM      MM  UU      UU  LL
                                 SS      II      MM      MM  UU      UU  LL
                         SSSSSSSS      IIIIII    MM      MM  UUUUUUUUUU  LLLLLLLLLL
                         SSSSSSSS      IIIIII    MM      MM  UUUUUUUUUU  LLLLLLLLLL

                           OOOOOO    UU      UU  TTTTTTTTTT      ;;;;        11      222222
                           OOOOOO    UU      UU  TTTTTTTTTT      ;;;;        11      222222
                         OO      OO  UU      UU      TT          ;;;;      1111    22      22
                         OO      OO  UU      UU      TT          ;;;;      1111    22      22
                         OO      OO  UU      UU      TT                      11            22
                         OO      OO  UU      UU      TT                      11            22
                         OO      OO  UU      UU      TT                      11          22
                         OO      OO  UU      UU      TT          ;;;;        11          22
                         OO      OO  UU      UU      TT          ;;;;        11        22
                         OO      OO  UU      UU      TT          ;;;;        11        22
                         OO      OO  UU      UU      TT          ;;;;        11      22
                 ....    OO      OO  UU      UU      TT            ;;        11      22
                 ....    OO      OO  UU      UU      TT            ;;        11      22
                 ....      OOOOOO    UUUUUUUUUU      TT          ;;      111111    2222222222
                 ....      OOOOOO    UUUUUUUUUU      TT          ;;      111111    2222222222

File _DUA1:[LANTOS]SIMUL.OUT;12 (528,162,0), last revised on 28-SEP-1988 10:46, is a 23 block sequential file owned by UIC
[GANDM,LANTOS].  The records are variable length with FORTRAN (FTN) carriage control.  The longest record is 116 bytes.

Job SIMUL (226) queued to SYS$PRINT on 28-SEP-1988 10:52 by user LANTOS, UIC [GANDM,LANTOS], under account GANDM at priority 100,
started on printer _TXA3: on 28-SEP-1988 10:56 from queue SYS$PRINT.

KKKKKKKKKK   0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000   KKKKKKKKKK
KKKKKKKKKK   0000000000000000000000000  Digital Equipment Corporation - VAX/VMS Version V4.6  00000000000000000000000000   KKKKKKKKKK
KKKKKKKKKK   0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000   KKKKKKKKKK
```

```
                                         INPUT DATA
                                  TURNING CIRCLE MANOEUVRE
************************************************************************************************
                  DESCRIPTION
                                                          VALUE                      UNITS
LENGTH BETWEEN PERPENDICULARS
LENGTH ON WATERLINE                                      137.00                      METERS
BREADTH                                                  137.00                      METERS
DRAFT AFT                                                 19.90                      METERS
DRAFT FWD                                                  6.10                      METERS
DISPLACEMENT                                               4.40                      METERS
BLOCK COEFFICIENT                                       9246.00                      TONNES
MIDSHIP SECTION COEFFICIENT                                0.64                      -----
WATERPLANE COEFFICIENT                                     0.88                      -----
RUDDER LATERAL AREA                                        0.85                      -----
PROPELLER DIAMETER                                        11.4                       SQ. METERS
PROPELLER PITCH/DIAMETER RATIO                             4.05                      METERS
PROPELLER EXPANDED BLADE AREA RATIO                        1.00                      -----
SHAFT HORSEPOWER                                           0.80                      -----
************************************************************************************************
                                                         9888.0                      KW
                                 SHIP SPEED - POWER DATA
 SPEED      WAVE        APPEND       BULB BOW     TRANSOM      CORR.       FRICTION      TOTAL       EFFECTIVE
(KNOTS)    RESIST       RESIST        RESIST       RESIST      RESIST       RESIST       RESIST      HORSEPOWER
            (KN)         (KN)          (KN)         (KN)        (KN)         (KN)         (KN)         (KW)
************************************************************************************************
 14.0    0.389E+02    0.266E+01    0.364E+02    0.000E+00    0.381E+02    0.129E+03    0.285E+03    0.205E+04
 15.0    0.624E+02    0.303E+01    0.381E+02    0.000E+00    0.437E+02    0.147E+03    0.340E+03    0.262E+04
 16.0    0.953E+02    0.342E+01    0.395E+02    0.000E+00    0.497E+02    0.166E+03    0.405E+03    0.334E+04
 17.0    0.139E+03    0.383E+01    0.408E+02    0.000E+00    0.562E+02    0.186E+03    0.484E+03    0.423E+04
 18.0    0.188E+03    0.426E+01    0.420E+02    0.000E+00    0.630E+02    0.207E+03    0.568E+03    0.526E+04
 19.0    0.249E+03    0.471E+01    0.431E+02    0.000E+00    0.701E+02    0.229E+03    0.667E+03    0.652E+04
 [redacted]  [redacted]  [redacted]  [redacted]  [redacted]  [redacted]  [redacted]    0.803E+03    0.827E+04
 21.0   0.478E+03   0.569E+01   0.448E+02   0.000E+00   0.857E+02   0.276E+03   0.977E+03    0.106E+05
 22.0   0.608E+03   0.621E+01   0.456E+02   0.000E+00   0.940E+02   0.301E+03   0.115E+04    0.130E+05
 23.0   0.696E+03   0.675E+01   0.463E+02   0.000E+00   0.103E+03   0.328E+03   0.128E+04    0.152E+05
 24.0   0.746E+03   0.731E+01   0.469E+02   0.000E+00   0.112E+03   0.355E+03   0.138E+04    0.170E+05
WAKE FRACTION =  0.150
THRUST DEDUCTION FRACTION =  0.195
FORM FACTOR OF THE HULL =  0.312
The friction resistance in the above table was
multiplied by (1.+CFORM) to obtain the total
resistance.
************************************************************************************************************
  TIME       LOCAL        LOCAL         LOCAL          GLOBAL         GLOBAL
            X-SPEED      Y-SPEED     SHIP SPEED     X-POSITION     Y-POSITION     YAW ANGLE   ROLL ANGLE   PROPELLER
  (SECS)    (KNOTS)      (KNOTS)       (KNOTS)       (METERS)       (METERS)                                SPEED
                                                                                  (DEGREES)    (DEGREES)     (RPM)
************************************************************************************************************
    0.0      18.99        0.00         18.99            0.00           0.00          0.0          0.0       169.8
   10.0      18.65        0.81         18.67           97.11           0.35         -2.3         -0.3       168.7
   20.0      17.24        2.53         17.43          190.16          -3.16        -14.7          2.7       163.5
   30.0      15.50        3.28         15.84          273.21         -22.96        -33.7          4.1       156.6
   40.0      13.91        3.36         14.31          339.53         -62.37        -53.8          4.0       150.4
   50.0      12.64        3.22         13.05          385.04        -115.49        -73.1          3.5       145.6
   60.0      11.66        3.05         12.05          409.51        -174.83        -91.2          3.1       141.9
   70.0      10.90        2.90         11.28          414.88        -234.29       -108.2          2.7       139.2
   80.0      10.31        2.78         10.67          403.91        -289.42       -124.4          2.4       137.1
   90.0       9.84        2.68         10.20          379.66        -337.09       -139.9          2.2       135.5
  100.0       9.47        2.60          9.83          345.22        -375.16       -155.0          2.0       134.2
  110.0       9.18        2.54          9.53          303.67        -402.26       -169.6          1.9       133.2
  120.0       8.95        2.49          9.28          257.98        -417.73       -184.0          1.8       132.4
  130.0       8.75        2.45          9.09          211.00        -421.46       -198.1          1.8       131.8
  140.0       8.60        2.41          8.93          165.38        -413.91       -212.0          1.7       131.3
  150.0       8.47        2.39          8.81          123.56        -395.99       -225.8          1.6       130.9
  160.0       8.37        2.37          8.70           87.61        -369.06       -239.4          1.6       130.5
```

```
     170.0       8.29       2.35       8.62        59.28     -334.83     -253.0       1.6        130.3
     180.0       8.22       2.33       8.55        39.87     -295.31     -266.4       1.6        130.0
     190.0       8.16       2.32       8.49        30.21     -252.67     -279.8       1.5        129.9
     200.0       8.12       2.31       8.44        30.65     -209.23     -293.1       1.5        129.7
     210.0       8.08       2.31       8.40        40.99     -167.26     -306.4       1.5        129.6
     220.0       8.05       2.30       8.37        60.61     -128.94     -319.7       1.5        129.5
     230.0       8.02       2.29       8.35        88.36      -96.23     -332.9       1.5        129.4
     240.0       8.00       2.29       8.32       122.75      -70.78     -346.1       1.5        129.3
     250.0       7.99       2.29       8.31       161.95      -53.88     -359.2       1.5        129.3
     260.0       7.97       2.28       8.29       203.88      -46.36     -372.4       1.5        129.2
END OF TURNING CIRCLE MANOEUVRE

                              RESULTS FROM TIME SIMULATION ANALYSIS
                                    TURNING CIRCLE MANOEUVRE
******************************************************************************************
                   DESCRIPTION                                     VALUE              UNITS
------------------------------------------------------------------------------------------
STEADY TURNING SPEED                                                8.30              KNOTS
NON-DIMENSIONAL ADVANCE (ADVANCE/LPP)                               2.99              -----
NON-DIMENSIONAL TRANSFER (TRANSFER/LPP)                             1.28              -----
NON-DIMENSIONAL TACTICAL DIAMETER (TAC. DIA./LPP)                   3.03              -----
NON-DIMENSIONAL STEADY TURNING DIAMETER (STDY. DIA./LPP)            2.65              -----
******************************************************************************************

                              RESULTS FROM THE EMPIRICAL ANALYSIS
                                    TURNING CIRCLE MANOEUVRE
******************************************************************************************
                   DESCRIPTION                                     VALUE              UNITS
------------------------------------------------------------------------------------------
STEADY TURNING SPEED                                               12.19              KNOTS
NON-DIMENSIONAL ADVANCE (ADVANCE/LPP)                               2.91              -----
```

```
NON-DIMENSIONAL TRANSFER (TRANSFER/LPP)                                  1.51            -----
NON-DIMENSIONAL TACTICAL DIAMETER (TAC. DIA./LPP)                        3.52            -----
NON-DIMENSIONAL STEADY TURNING DIAMETER (STDY. DIA./LPP)                 3.38            -----
STANDARD DEVIATION OF (VST/VX1) = 0.166
STANDARD DEVIATION OF (ADV/LPP) = 0.188
STANDARD DEVIATION OF (TR/LPP) = 0.129
STANDARD DEVIATION OF (TACDIA/LPP) = 0.066
STANDARD DEVIATION OF (STDYDIA/LPP) = 0.271
MESSAGES FOR EMPIRICAL TURNING CIRCLE ANALYSIS
_____________________________________________
BLOCK COEFFICIENT IS OUTSIDE THE RANGE OF (.42 <= CB <= .62)
RATIO (ASUB/(LPP*T)) IS OUTSIDE THE RANGE OF (-.1 <= RATIO <= 0.0)
****************************************************************************************************

                                          CRASH STOP MANOEUVRE
****************************************************************************************************
                         DESCRIPTION                                   VALUE                UNITS
_____________________________________________________________________________________________________
INITIAL SPEED OF SHIP                                                   18.99               KNOTS
INITIAL RESISTANCE OF SHIP                                             666.5                 KN
MAXIMUM ASTERN THRUST                                                  571.2                 KN
NON-DIMENSIONAL HEAD REACH (REACH/LPP)                                   4.48               -----
****************************************************************************************************
```

```
CCCCCCCCCC   9999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999
CCCCCCCCCC   9999999999999999999999999999  Digital Equipment Corporation - VAX/VMS Version V4.6  9999999999999999999999999999   CCCCCCCCCC
CCCCCCCCCC   9999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999   CCCCCCCCCC
                                                                                                                                  CCCCCCCCCC

                              L       AAA   N   N  TTTTT   OOO   SSSS
                              L      A   A  N   N    T    O   O S
                              L      A   A  NN  N    T    O   O S
                              L      A   A  N N N    T    O   O  SSS
                              L      AAAAA  N  NN    T    O   O     S
                              L      A   A  N   N    T    O   O     S
                              LLLLL  A   A  N   N    T     OOO  SSSS

              FFFFFFFFFF  RRRRRRRR    TTTTTTTTTT      11        000000    ZZZZZZZZZZ    IIIIII      GGGGGGGG
              FFFFFFFFFF  RRRRRRRR    TTTTTTTTTT      11        000000    ZZZZZZZZZZ    IIIIII      GGGGGGGG
              FF          RR      RR      TT        1111      00      00          ZZ      II      GG
              FF          RR      RR      TT        1111      00      00          ZZ      II      GG
              FF          RR      RR      TT          11      00    0000        ZZ        II      GG
              FF          RR      RR      TT          11      00    0000        ZZ        II      GG
              FFFFFFFF    RRRRRRRR        TT          11      00  00  00      ZZ          II      GG
              FFFFFFFF    RRRRRRRR        TT          11      00  00  00      ZZ          II      GG
              FF          RR  RR          TT          11      0000    00    ZZ            II      GG    GGGGGG
              FF          RR  RR          TT          11      0000    00    ZZ            II      GG    GGGGGG
              FF          RR    RR        TT          11      00      00  ZZ              II      GG        GG
              FF          RR    RR        TT          11      00      00  ZZ              II      GG        GG
              FF          RR      RR      TT        111111      000000    ZZZZZZZZZZ    IIIIII      GGGGGG
              FF          RR      RR      TT        111111      000000    ZZZZZZZZZZ    IIIIII      GGGGGG

                                DDDDDDDD      AAAAAA    TTTTTTTTTT    ;;;;        11
                                DDDDDDDD      AAAAAA    TTTTTTTTTT    ;;;;        11
                                DD      DD  AA      AA      TT        ;;;;      1111
                                DD      DD  AA      AA      TT        ;;;;      1111
                                DD      DD  AA      AA      TT                    11
                                DD      DD  AA      AA      TT                    11
                                DD      DD  AA      AA      TT        ;;;;        11
                                DD      DD  AA      AA      TT        ;;;;        11
                                DD      DD  AAAAAAAAAA      TT        ;;;;        11
                                DD      DD  AAAAAAAAAA      TT        ;;;;        11
                          ::::  DD      DD  AA      AA      TT          ;;        11
                          ::::  DD      DD  AA      AA      TT          ;;        11
                          ::::  DDDDDDDD    AA      AA      TT        ;;        111111
                          ::::  DDDDDDDD    AA      AA      TT        ;;        111111

File _DUA1:[LANTOS]FRT10ZIG.DAT;1 (981,112,0), last revised on 28-SEP-1988 10:12, is a 1 block sequential file owned by UIC
[GANDM,LANTOS].  The records are variable length with implied (CR) carriage control.  The longest record is 57 bytes.

Job ALGOB-15BPIR (221) queued to SYS$PRINT on 28-SEP-1988 10:14 by user LANTOS, UIC [GANDM,LANTOS], under account GANDM at priority
100, started on printer _TXA3: on 28-SEP-1988 10:27 from queue SYS$PRINT.

CCCCCCCCCC   9999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999
CCCCCCCCCC   9999999999999999999999999999  Digital Equipment Corporation - VAX/VMS Version V4.6  9999999999999999999999999999   CCCCCCCCCC
CCCCCCCCCC   9999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999   CCCCCCCCCC
                                                                                                                                  CCCCCCCCCC
```

```
1025.,1.1889E-6,1,9.4,5.712E5
137.,137.,19.9,6.1,4.4,.64,.88,.85,9.246E6
2.33,-11.04,0.,0.,9.77,0.,0.,0.,2.83,0.,0.,0.,0.,0.
0.15,0.,-69.,4.2,0.15,11.4,5.69,1.55,5.19,8.25,0.,11,150.
0.,0,1,0.,0.,8.,3.,1
45.6,1.4
2,4000.,1.,10.,14,4.05,1.,.8,4,9.888E6,2,-68.,7.3
9.77,2,1,8.,2.,0.5.
```

```
JJJJJJJJJJ   0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
JJJJJJJJJJ   000000000000000000000000000  Digital Equipment Corporation - VAX/VMS Version V4.6  000000000000000000000000000   JJJJJJJJJJ
JJJJJJJJJJ   0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000   JJJJJJJJJJ
                                                                                                                                JJJJJJJJJJ

                        L       AAA   N   N  TTTTT   OOO   SSSS
                        L      A   A  N   N    T    O   O S
                        L      A   A  NN  N    T    O   O S
                        L      A   A  N N N    T    O   O  SSS
                        L      AAAAA  N  NN    T    O   O     S
                        L      A   A  N   N    T    O   O     S
                        LLLLL  A   A  N   N    T     OOO  SSSS

                  SSSSSSSS   IIIIII   MM        MM  UU        UU  LL
                  SSSSSSSS   IIIIII   MM        MM  UU        UU  LL
                SS             II     MMMM    MMMM  UU        UU  LL
                SS             II     MMMM    MMMM  UU        UU  LL
                SS             II     MM  MM  MM    UU        UU  LL
                SS             II     MM  MM  MM    UU        UU  LL
                  SSSSSS       II     MM        MM  UU        UU  LL
                  SSSSSS       II     MM        MM  UU        UU  LL
                        SS     II     MM        MM  UU        UU  LL
                        SS     II     MM        MM  UU        UU  LL
                        SS     II     MM        MM  UU        UU  LL
                        SS     II     MM        MM  UU        UU  LL
                SSSSSSSS     IIIIII   MM        MM  UUUUUUUUUU    LLLLLLLLLL
                SSSSSSSS     IIIIII   MM        MM  UUUUUUUUUU    LLLLLLLLLL

                  000000     UU        UU  TTTTTTTTTT      ;;;;        11        333333
                  000000     UU        UU  TTTTTTTTTT      ;;;;        11        333333
                00      00   UU        UU      TT          ;;;;      1111      33      33
                00      00   UU        UU      TT          ;;;;      1111      33      33
                00      00   UU        UU      TT                      11              33
                00      00   UU        UU      TT                      11              33
                00      00   UU        UU      TT                      11            33
                00      00   UU        UU      TT          ;;;;        11            33
                00      00   UU        UU      TT          ;;;;        11              33
                00      00   UU        UU      TT          ;;;;        11              33
        ....    00      00   UU        UU      TT          ;;;;        11      33      33
        ....    00      00   UU        UU      TT            ;;        11      33      33
        ....      000000     UUUUUUUUUU        TT            ;;      111111      333333
                  000000     UUUUUUUUUU        TT          ;;        111111      333333

File _DUA1:[LANTOS]SIMUL.OUT;13 (552,117,0), last revised on 28-SEP-1988 10:46, is a 20 block sequential file owned by UIC
[QANDM,LANTOS].  The records are variable length with FORTRAN (FTN) carriage control.  The longest record is 116 bytes.

Job SIMUL (226) queued to SYS$PRINT on 28-SEP-1988 10:52 by user LANTOS, UIC [QANDM,LANTOS], under account QANDM at priority 100,
started on printer _TXA3: on 28-SEP-1988 10:55 from queue SYS$PRINT.

JJJJJJJJJJ   0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
JJJJJJJJJJ   000000000000000000000000000  Digital Equipment Corporation - VAX/VMS Version V4.6  000000000000000000000000000   JJJJJJJJJJ
JJJJJJJJJJ   0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000   JJJJJJJJJJ
                                                                                                                                JJJJJJJJJJ
```

```
                                        INPUT DATA
                                     ZIGZAG MANOEUVRE
*****************************************************************************************
                    DESCRIPTION                                  VALUE            UNITS
-----------------------------------------------------------------------------------------
LENGTH BETWEEN PERPENDICULARS                                   137.00           METERS
LENGTH ON WATERLINE                                             137.00           METERS
BREADTH                                                          19.90           METERS
DRAFT AFT                                                         6.10           METERS
DRAFT FWD                                                         4.40           METERS
DISPLACEMENT                                                   9246.00           TONNES
BLOCK COEFFICIENT                                                 0.64           -----
MIDSHIP SECTION COEFFICIENT                                       0.88           -----
WATERPLANE COEFFICIENT                                            0.85           -----
RUDDER LATERAL AREA                                              11.4            SQ. METERS
PROPELLER DIAMETER                                                4.05           METERS
PROPELLER PITCH/DIAMETER RATIO                                    1.00           -----
PROPELLER EXPANDED BLADE AREA RATIO                               0.80           -----
SHAFT HORSEPOWER                                               9888.0             KW
*****************************************************************************************
                               SHIP SPEED - POWER DATA
 SPEED     WAVE      APPEND    BULB BOW   TRANSOM     CORR.    FRICTION    TOTAL     EFFECTIVE
         RESIST     RESIST     RESIST     RESIST     RESIST     RESIST    RESIST    HORSEPOWER
(KNOTS)   (KN)       (KN)       (KN)       (KN)       (KN)       (KN)      (KN)        (KW)
*****************************************************************************************
 14.0   0.389E+02  0.266E+01  0.364E+02  0.000E+00  0.381E+02  0.129E+03  0.285E+03  0.205E+04
 15.0   0.624E+02  0.303E+01  0.381E+02  0.000E+00  0.437E+02  0.147E+03  0.340E+03  0.262E+04
 16.0   0.953E+02  0.342E+01  0.395E+02  0.000E+00  0.497E+02  0.166E+03  0.405E+03  0.334E+04
 17.0   0.139E+03  0.383E+01  0.408E+02  0.000E+00  0.562E+02  0.186E+03  0.484E+03  0.423E+04
 18.0   0.188E+03  0.426E+01  0.420E+02  0.000E+00  0.630E+02  0.207E+03  0.568E+03  0.526E+04
 19.0   0.249E+03  0.471E+01  0.431E+02  0.000E+00  0.701E+02  0.229E+03  0.667E+03  0.652E+04
 20.0   0.346E+03  0.519E+01  0.440E+02  0.000E+00  0.777E+02  0.252E+03  0.803E+03  0.827E+04
```

```
   21.0   0.478E+03   0.569E+01   0.448E+02   0.000E+00   0.857E+02   0.276E+03   0.977E+03   0.106E+05
   22.0   0.608E+03   0.621E+01   0.456E+02   0.000E+00   0.940E+02   0.301E+03   0.115E+04   0.130E+05
   23.0   0.696E+03   0.675E+01   0.463E+02   0.000E+00   0.103E+03   0.328E+03   0.128E+04   0.152E+05
   24.0   0.746E+03   0.731E+01   0.469E+02   0.000E+00   0.112E+03   0.355E+03   0.138E+04   0.170E+05
 WAKE FRACTION =  0.150
 THRUST DEDUCTION FRACTION =  0.195
 FORM FACTOR OF THE HULL =  0.312
 The friction resistance in the above table was
 multiplied by (1.+CFORM) to obtain the total
 resistance.
 ************************************************************************************************************
   TIME      LOCAL      LOCAL        LOCAL          GLOBAL         GLOBAL
            X-SPEED    Y-SPEED    SHIP SPEED      X-POSITION     Y-POSITION    YAW ANGLE   ROLL ANGLE   PROPELLER
  (SECS)    (KNOTS)    (KNOTS)     (KNOTS)         (METERS)       (METERS)     (DEGREES)   (DEGREES)     SPEED
                                                                                                         (RPM)
 ************************************************************************************************************
    0.0      18.99       0.00       18.99            0.00           0.00          0.0         0.0        169.8
   10.0      18.76      -0.61       18.77           97.20          -0.24          2.0        -0.4        169.0
   20.0      18.42      -1.42       18.47          192.97           3.06          9.0        -1.7        167.6
 RUDDER ANGLE IS  -10.00000

   30.0      18.07      -1.27       18.12          285.90          17.42         17.3        -2.7        166.1
   40.0      17.90      -0.42       17.91          374.73          43.37         19.8        -1.1        165.4
   50.0      17.79       0.49       17.80          461.56          73.26         17.2         0.1        165.0
   60.0      17.60       1.28       17.64          548.69         100.15         10.6         1.3        164.2
   70.0      17.28       1.79       17.37          637.01         117.65          1.2         2.1        163.0
   80.0      16.87       2.07       17.00          725.26         121.04        -10.0         2.6        161.4
 RUDDER ANGLE IS   10.00000

   90.0      16.62       1.44       16.69          810.68         107.80        -19.1         2.8        160.2
  100.0      16.60       0.57       16.61          892.20          81.95        -22.1         1.3        160.1
  110.0      16.65      -0.31       16.66          972.03          51.15        -20.3         0.2        160.4
  120.0      16.62      -1.11       16.66         1052.51          21.65        -14.4        -0.9        160.3
 [illegible] [illegible]45  -1[illegible]  [illegible].54  [illegible]4.9[illegible]  [illegible].55  [illegible]  -1.[illegible]  139.8
```

```
    140.0     16.19     -1.96      16.31       1218.79      -10.57      5.0      -2.3      158.6
    150.0     15.94     -1.84      16.05       1301.69       -5.42     16.0      -3.2      157.6
RUDDER ANGLE IS  -10.00000

    160.0     15.90     -1.01      15.93       1381.19       14.83     21.9      -1.7      157.3
    170.0     16.02     -0.23      16.02       1458.17       43.49     22.7      -0.7      157.8
    180.0     16.13      0.58      16.14       1534.87       74.53     19.4       0.2      158.3
    190.0     16.13      1.25      16.18       1613.17      102.54     12.8       1.2      158.3
    200.0     16.01      1.69      16.10       1693.79      122.32      3.8       1.9      157.9
    210.0     15.80      1.94      15.92       1775.73      129.83     -6.7       2.3      157.1
    220.0     15.65      1.65      15.73       1856.64      122.60    -16.6       2.5      156.4
RUDDER ANGLE IS   10.00000

    230.0     15.69      0.81      15.71       1934.62      101.85    -21.2       1.3      156.5
    240.0     15.84      0.00      15.84       2010.90       74.29    -20.8       0.4      157.1
    250.0     15.94     -0.82      15.96       2087.61       45.79    -16.3      -0.5      157.5
    260.0     15.92     -1.43      15.98       2166.27       21.97     -8.7      -1.4      157.5
    270.0     15.77     -1.81      15.87       2246.97        7.88      1.0      -2.0      156.9
END OF ZIGZAG SIMULATION

                          RESULTS FROM TIME SIMULATION ANALYSIS
                                   ZIGZAG MANOEUVRE
******************************************************************************************
                  DESCRIPTION                                 VALUE                UNITS
------------------------------------------------------------------------------------------
 OVERSHOOT ANGLE                                               9.78               DEGREES
 NON-DIMENSIONAL OVERSHOOT WIDTH OF PATH (WIDTH/LPP)           0.86               -----
 PERIOD BETWEEN 1st RUDDER CHANGE AND 3rd RUDDER CHANGE      123.0                SECS.
 NON-DIMENSIONAL REACH (REACH/LPP)                             4.78               -----
******************************************************************************************
```

```
                         RESULTS FROM THE EMPIRICAL ANALYSIS

                                CRASH STOP MANOEUVRE
*******************************************************************************
               DESCRIPTION                        VALUE              UNITS
-------------------------------------------------------------------------------
INITIAL SPEED OF SHIP                              18.99             KNOTS
INITIAL RESISTANCE OF SHIP                        666.5               KN
MAXIMUM ASTERN THRUST                             571.2               KN
NON-DIMENSIONAL HEAD REACH (REACH/LPP)           . 4.48              -----
*******************************************************************************
```

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DDDDDDDDDD   999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999   DDDDDDDDDD
DDDDDDDDDD   9999999999999999999999999  Digital Equipment Corporation - VAX/VMS Version V4.6  9999999999999999999999999   DDDDDDDDDD
DDDDDDDDDD   999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999   DDDDDDDDDD

                                L       AAA   N   N  TTTTT   OOO   SSSS
                                L      A   A  N   N    T    O   O S
                                L      A   A  NN  N    T    O   O S
                                L      A   A  N N N    T    O   O  SSS
                                L      AAAAA  N  NN    T    O   O     S
                                L      A   A  N   N    T    O   O     S
                                LLLLL  A   A  N   N    T     OOO  SSSS

        FFFFFFFFFF  RRRRRRRR    TTTTTTTTTT      11    5555555555   SSSSSSSS   PPPPPPPP    IIIIII   RRRRRRRR
        FFFFFFFFFF  RRRRRRRR    TTTTTTTTTT      11    5555555555   SSSSSSSS   PPPPPPPP    IIIIII   RRRRRRRR
        FF          RR      RR      TT        1111    55          SS          PP      PP    II     RR      RR
        FF          RR      RR      TT        1111    55          SS          PP      PP    II     RR      RR
        FF          RR      RR      TT          11    555555      SS          PP      PP    II     RR      RR
        FF          RR      RR      TT          11    555555      SS          PP      PP    II     RR      RR
        FFFFFFFF    RRRRRRRR        TT          11          55     SSSSSS     PPPPPPPP      II     RRRRRRRR
        FFFFFFFF    RRRRRRRR        TT          11          55     SSSSSS     PPPPPPPP      II     RRRRRRRR
        FF          RR  RR          TT          11            55         SS   PP            II     RR  RR
        FF          RR  RR          TT          11            55         SS   PP            II     RR  RR
        FF          RR    RR        TT          11    55      55         SS   PP            II     RR    RR
        FF          RR    RR        TT          11    55      55         SS   PP            II     RR    RR
        FF          RR      RR      TT        111111    555555    SSSSSSSS    PP          IIIIII   RR      RR
        FF          RR      RR      TT        111111    555555    SSSSSSSS    PP          IIIIII   RR      RR

                          DDDDDDDD      AAAAAA      TTTTTTTTTT     ;;;;       11
                          DDDDDDDD      AAAAAA      TTTTTTTTTT     ;;;;       11
                          DD      DD  AA      AA        TT         ;;;;     1111
                          DD      DD  AA      AA        TT         ;;;;     1111
                          DD      DD  AA      AA        TT                    11
                          DD      DD  AA      AA        TT                    11
                          DD      DD  AAAAAAAAAA        TT         ;;;;       11
                          DD      DD  AAAAAAAAAA        TT         ;;;;       11
                  ::::    DD      DD  AA      AA        TT          ;;        11
                  ::::    DD      DD  AA      AA        TT          ;;        11
                  ::::    DDDDDDDD    AA      AA        TT         ;;       111111
                          DDDDDDDD    AA      AA        TT         ;;       111111

File _DUA1:[LANTOS]FRT15SPIR.DAT;1 (944,83,0), last revised on 28-SEP-1988 10:12, is a 1 block sequential file owned by UIC
[OANDM,LANTOS].  The records are variable length with implied (CR) carriage control.  The longest record is 57 bytes.

Job ALGOB-15SPIR (221) queued to SYS$PRINT on 28-SEP-1988 10:14 by user LANTOS, UIC [OANDM,LANTOS], under account OANDM at priority
100, started on printer _TXA3: on 28-SEP-1988 10:27 from queue SYS$PRINT.

DDDDDDDDDD   999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999   DDDDDDDDDD
DDDDDDDDDD   9999999999999999999999999  Digital Equipment Corporation - VAX/VMS Version V4.6  9999999999999999999999999   DDDDDDDDDD
DDDDDDDDDD   999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999   DDDDDDDDDD
```

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```
1025.,1.1889E-6,1,9.4,5.712E5
137.,137.,19.9,6.1,4.4,.64,.88,.85,9.246E6
2.33,-11.04,0.,0.,9.77,0.,0.,0.,2.83,0.,0.,0.,0.,0.
0.15,0.,-69.,4.2,0.15,11.4,5.69,1.55,5.19,8.25,0.,11,150.
0.,0,1,0.,0.,8.,3.,1
45.6,1.4
3,4000.,1.,15.,14,4.05,1.,.8,4,9.888E6,2,-68.,7.3
9.77,2,1,8.,2.,0,5.
```

```
IIIIIIIIIII    0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000    IIIIIIIIIII
IIIIIIIIIII    000000000000000000000000  Digital Equipment Corporation - VAX/VMS Version V4.6  0000000000000000000000000    IIIIIIIIIII
IIIIIIIIIII    0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000    IIIIIIIIIII

                                  L        AAA    N   N   TTTTT    OOO    SSSS
                                  L       A   A   N   N     T     O   O  S
                                  L       A   A   NN  N     T     O   O  S
                                  L       A   A   N N N     T     O   O   SSS
                                  L       AAAAA   N  NN     T     O   O      S
                                  L       A   A   N   N     T     O   O      S
                                  LLLLL   A   A   N   N     T      OOO   SSSS

                         SSSSSSSS     IIIIII     MM      MM   UU      UU   LL
                         SSSSSSSS     IIIIII     MM      MM   UU      UU   LL
                       SS               II       MMMM  MMMM   UU      UU   LL
                       SS               II       MMMM  MMMM   UU      UU   LL
                       SS               II       MM  MM  MM   UU      UU   LL
                       SS               II       MM  MM  MM   UU      UU   LL
                         SSSSSS         II       MM      MM   UU      UU   LL
                         SSSSSS         II       MM      MM   UU      UU   LL
                               SS       II       MM      MM   UU      UU   LL
                               SS       II       MM      MM   UU      UU   LL
                               SS       II       MM      MM   UU      UU   LL
                               SS       II       MM      MM   UU      UU   LL
                       SSSSSSSS       IIIIII     MM      MM   UUUUUUUUUU   LLLLLLLLLL
                       SSSSSSSS       IIIIII     MM      MM   UUUUUUUUUU   LLLLLLLLLL

                         OOOOOO     UU      UU   TTTTTTTTTT       ;;;;           11      44      44
                         OOOOOO     UU      UU   TTTTTTTTTT       ;;;;           11      44      44
                       OO      OO   UU      UU       TT           ;;;;         1111      44      44
                       OO      OO   UU      UU       TT           ;;;;         1111      44      44
                       OO      OO   UU      UU       TT                          11      44      44
                       OO      OO   UU      UU       TT                          11      44      44
                       OO      OO   UU      UU       TT           ;;;;           11      4444444444
                       OO      OO   UU      UU       TT           ;;;;           11      4444444444
                       OO      OO   UU      UU       TT           ;;;;           11              44
                       OO      OO   UU      UU       TT           ;;;;           11              44
               ....    OO      OO   UU      UU       TT             ;;           11              44
               ....    OO      OO   UU      UU       TT             ;;           11              44
               ....      OOOOOO     UUUUUUUUUU       TT           ;;           111111            44
               ....      OOOOOO     UUUUUUUUUU       TT           ;;           111111            44

File _DUA1:[LANTOS]SIMUL.OUT;14 (875,85,0), last revised on 28-SEP-1988 10:47, is a 64 block sequential file owned by UIC
[QANDM,LANTOS].  The records are variable length with FORTRAN (FTN) carriage control.  The longest record is 116 bytes.

Job SIMUL (226) queued to SYS$PRINT on 28-SEP-1988 10:52 by user LANTOS, UIC [QANDM,LANTOS], under account QANDM at priority 100,
started on printer _TXA3: on 28-SEP-1988 10:54 from queue SYS$PRINT.

IIIIIIIIIII    0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000    IIIIIIIIIII
IIIIIIIIIII    000000000000000000000000  Digital Equipment Corporation - VAX/VMS Version V4.6  0000000000000000000000000    IIIIIIIIIII
IIIIIIIIIII    0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000    IIIIIIIIIII
```

```
                                    INPUT DATA
                                 SPIRAL MANOEUVRE
****************************************************************************************
                   DESCRIPTION                                 VALUE              UNITS
----------------------------------------------------------------------------------------
LENGTH BETWEEN PERPENDICULARS                                 137.00             METERS
LENGTH ON WATERLINE                                           137.00             METERS
BREADTH                                                        19.90             METERS
DRAFT AFT                                                       6.10             METERS
DRAFT FWD                                                       4.40             METERS
DISPLACEMENT                                                 9246.00             TONNES
BLOCK COEFFICIENT                                               0.64             -----
MIDSHIP SECTION COEFFICIENT                                     0.88             -----
WATERPLANE COEFFICIENT                                          0.85             -----
RUDDER LATERAL AREA                                            11.4              SQ. METERS
PROPELLER DIAMETER                                              4.05             METERS
PROPELLER PITCH/DIAMETER RATIO                                  1.00             -----
PROPELLER EXPANDED BLADE AREA RATIO                             0.80             -----
SHAFT HORSEPOWER                                             9888.0               KW
****************************************************************************************
                          SHIP SPEED - POWER DATA
SPEED     WAVE       APPEND     BULB BOW   TRANSOM     CORR.     FRICTION    TOTAL      EFFECTIVE
(KNOTS)  RESIST      RESIST      RESIST     RESIST     RESIST     RESIST     RESIST     HORSEPOWER
          (KN)        (KN)        (KN)       (KN)       (KN)       (KN)       (KN)        (KW)
****************************************************************************************
 14.0   0.389E+02  0.266E+01  0.364E+02  0.000E+00  0.381E+02  0.129E+03  0.285E+03  0.205E+04
 15.0   0.624E+02  0.303E+01  0.381E+02  0.000E+00  0.437E+02  0.147E+03  0.340E+03  0.262E+04
 16.0   0.953E+02  0.342E+01  0.395E+02  0.000E+00  0.497E+02  0.166E+03  0.405E+03  0.334E+04
 17.0   0.139E+03  0.383E+01  0.408E+02  0.000E+00  0.562E+02  0.186E+03  0.484E+03  0.423E+04
 18.0   0.188E+03  0.426E+01  0.420E+02  0.000E+00  0.630E+02  0.207E+03  0.568E+03  0.526E+04
 [redacted]
 20.0   [redacted]  0.519E+01  0.440E+02  0.000E+00  0.777E+02  0.252E+03  0.803E+03  0.827E+04
```

```
      21.0     0.478E+03   0.569E+01   0.448E+02   0.000E+00   0.857E+02   0.276E+03   0.977E+03    0.106E+05
      22.0     0.608E+03   0.621E+01   0.456E+02   0.000E+00   0.940E+02   0.301E+03   0.115E+04    0.130E+05
      23.0     0.696E+03   0.675E+01   0.463E+02   0.000E+00   0.103E+03   0.328E+03   0.128E+04    0.152E+05
      24.0     0.746E+03   0.731E+01   0.469E+02   0.000E+00   0.112E+03   0.355E+03   0.138E+04    0.170E+05
    WAKE FRACTION =  0.150
    THRUST DEDUCTION FRACTION =  0.195
    FORM FACTOR OF THE HULL =  0.312
    The friction resistance in the above table was
    multiplied by (1.+CFORM) to obtain the total
    resistance.
    ************************************************************************************************************
      TIME       LOCAL       LOCAL        LOCAL          GLOBAL          GLOBAL      YAW ANGLE    ROLL ANGLE    PROPELLER
                X-SPEED     Y-SPEED    SHIP SPEED      X-POSITION      Y-POSITION                                SPEED
     (SECS)     (KNOTS)     (KNOTS)     (KNOTS)         (METERS)        (METERS)     (DEGREES)    (DEGREES)      (RPM)
    ************************************************************************************************************
        0.0      18.99        0.00       18.99            0.00            0.00          0.0          0.0         169.8
       10.0      18.59       -1.06       18.62           96.81           -0.29          3.9         -1.3         168.4
       20.0      17.98       -2.04       18.09          191.06            6.05         14.5         -2.7         166.0
       30.0      17.20       -2.52       17.39          279.58           27.80         28.5         -3.4         162.9
       40.0      16.41       -2.67       16.63          357.22           67.62         43.7         -3.5         159.7
       50.0      15.70       -2.68       15.92          419.40          123.28         59.0         -3.4         156.9
       60.0      15.09       -2.62       15.32          463.37          190.22         74.0         -3.2         154.5
       70.0      14.59       -2.56       14.81          488.06          263.42         88.5         -3.0         152.5
       80.0      14.18       -2.50       14.40          493.75          338.11        102.7         -2.9         150.9
       90.0      13.84       -2.44       14.05          481.61          410.07        116.5         -2.7         149.6
      100.0      13.56       -2.40       13.77          453.49          475.70        129.9         -2.6         148.5
      110.0      13.33       -2.36       13.54          411.77          532.00        143.2         -2.5         147.7
      120.0      13.15       -2.32       13.35          359.17          576.67        156.2         -2.4         147.0
      130.0      12.99       -2.30       13.19          298.71          608.01        169.1         -2.4         146.4
   RUDDER ANGLE =   10.00000

      140.0      12.86       -2.28       13.06          233.52          625.01        181.8         -2.3         145.9
```

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```
   150.0    12.87    -2.09     13.03      166.62     627.12    193.6     -2.1      145.8
   160.0    12.93    -2.00     13.08      100.61     615.36    204.5     -2.0      146.0
   170.0    13.01    -1.95     13.16       37.78     590.98    215.1     -2.0      146.3
   180.0    13.10    -1.93     13.24      -19.74     555.11    225.6     -2.0      146.7
   190.0    13.17    -1.92     13.31      -69.99     509.00    236.1     -2.0      146.9
   200.0    13.24    -1.93     13.38     -111.19     454.18    246.6     -2.0      147.2
   210.0    13.31    -1.93     13.45     -141.83     392.44    257.1     -2.0      147.4
   220.0    13.36    -1.94     13.50     -160.74     325.86    267.7     -2.0      147.7
   230.0    13.41    -1.94     13.55     -167.14     256.67    278.2     -2.0      147.8
   240.0    13.45    -1.95     13.59     -160.68     187.27    288.9     -2.0      148.0
   250.0    13.48    -1.95     13.62     -141.48     120.06    299.5     -2.0      148.1
   260.0    13.51    -1.96     13.65     -110.11      57.40    310.2     -2.0      148.2
   270.0    13.54    -1.96     13.68      -67.60       1.54    320.8     -2.1      148.3
RUDDER ANGLE =    5.000000
   280.0    13.64    -1.79     13.75      -15.20     -45.51    330.8     -1.8      148.6
   290.0    13.80    -1.66     13.90       45.11     -83.02    339.6     -1.7      149.2
   300.0    13.97    -1.59     14.06      111.31    -110.90    348.0     -1.7      149.8
   310.0    14.14    -1.55     14.22      181.73    -128.85    356.1     -1.7      150.5
   320.0    14.29    -1.53     14.38      254.82    -136.56    364.2     -1.7      151.1
   330.0    14.44    -1.53     14.52      329.04    -133.81    372.2     -1.7      151.6
   340.0    14.57    -1.53     14.65      402.82    -120.51    380.3     -1.7      152.1
   350.0    14.68    -1.54     14.77      474.60     -96.75    388.3     -1.7      152.6
   360.0    14.79    -1.54     14.87      542.80     -62.85    396.5     -1.7      153.0
   370.0    14.88    -1.55     14.96      605.90     -19.34    404.6     -1.7      153.3
   380.0    14.95    -1.56     15.03      662.48      33.01    412.8     -1.7      153.6
   390.0    15.02    -1.57     15.10      711.22      93.21    421.1     -1.8      153.9
   400.0    15.08    -1.57     15.16      750.95     160.08    429.4     -1.8      154.1
RUDDER ANGLE =    0.0000000E+00
   410.0    15.15    [illegible]  15.22   [illegible]  [illegible]  [illegible]  [illegible]  154[illegible]
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    420.0    15.29    -1.23     15.34      800.08     308.36    443.8     -1.6      154.9
    430.0    15.46    -1.07     15.50      810.77     386.91    449.1     -1.3      155.6
    440.0    15.64    -0.94     15.67      813.86     467.00    453.7     -1.1      156.3
    450.0    15.83    -0.85     15.85      810.20     547.98    457.8     -1.0      157.0
    460.0    16.00    -0.77     16.02      800.43     629.35    461.6     -0.9      157.7
    470.0    16.16    -0.71     16.18      785.08     710.72    465.0     -0.8      158.3
    480.0    16.32    -0.66     16.33      764.60     791.79    468.2     -0.8      158.9
    490.0    16.46    -0.62     16.47      739.35     872.30    471.1     -0.7      159.5
    500.0    16.59    -0.58     16.60      709.66     952.01    473.9     -0.7      160.0
    510.0    16.71    -0.55     16.72      675.83    1030.76    476.5     -0.6      160.5
    520.0    16.82    -0.53     16.83      638.13    1108.37    479.0     -0.6      160.9
    530.0    16.92    -0.50     16.93      596.79    1184.71    481.4     -0.6      161.3
    540.0    17.01    -0.48     17.01      552.02    1259.66    483.6     -0.6      161.7
    550.0    17.09    -0.46     17.09      504.04    1333.11    485.8     -0.5      162.0
    560.0    17.16    -0.45     17.17      453.04    1404.97    487.9     -0.5      162.3
    570.0    17.23    -0.43     17.23      399.17    1475.17    490.0     -0.5      162.6
    580.0    17.29    -0.42     17.29      342.61    1543.63    492.0     -0.5      162.8
    590.0    17.34    -0.41     17.35      283.52    1610.30    493.9     -0.5      163.0
    600.0    17.39    -0.40     17.39      222.02    1675.13    495.8     -0.5      163.2
    610.0    17.43    -0.39     17.44      158.27    1738.06    497.6     -0.5      163.4
    620.0    17.47    -0.38     17.47       92.37    1799.06    499.4     -0.5      163.6
    630.0    17.51    -0.37     17.51       24.46    1858.10    501.1     -0.4      163.7
    640.0    17.54    -0.36     17.54      -45.35    1915.15    502.8     -0.4      163.8
    650.0    17.57    -0.36     17.57     -116.95    1970.18    504.5     -0.4      164.0
    660.0    17.59    -0.35     17.59     -190.24    2023.17    506.1     -0.4      164.1
RUDDER ANGLE =   -5.000000

    670.0    17.61    -0.28     17.61     -265.14    2074.09    507.6     -0.6      164.1
    680.0    17.61     0.12     17.62     -341.41    2122.99    507.2     -0.2      164.2
    690.0    17.60     0.57     17.61     -417.48    2172.23    504.3      0.4      164.1
    700.0    17.54     0.95     17.57     -491.24    2224.65    499.6      1.0      163.9
    710.0     17.43       1.24       17.47       -560.40      2282.43      493.2       1.4        163.5
    720.0     17.27       1.44       17.33       -622.58      2346.79      485.8       1.8        162.9
    730.0     17.10       1.57       17.17       -675.63      2417.87      477.6       2.0        162.2
    740.0     16.92       1.64       16.99       -717.77      2494.90      468.9       2.1        161.4
    750.0     16.74       1.68       16.82       -747.72      2576.47      460.1       2.1        160.7
    760.0     16.57       1.69       16.66       -764.69      2660.81      451.1       2.1        160.1
    770.0     16.43       1.70       16.51       -768.38      2745.96      442.1       2.1        159.5
    780.0     16.29       1.69       16.38       -758.87      2829.94      433.1       2.1        158.9
    790.0     16.18       1.69       16.27       -736.59      2910.81      424.2       2.1        158.5
    800.0     16.08       1.68       16.17       -702.29      2986.76      415.3       2.0        158.1
    810.0     15.99       1.67       16.08       -656.95      3056.11      406.4       2.0        157.7
    820.0     15.92       1.66       16.01       -601.78      3117.38      397.6       2.0        157.4
    830.0     15.86       1.65       15.94       -538.17      3169.29      388.9       2.0        157.2
    840.0     15.80       1.65       15.89       -467.68      3210.77·     380.2       2.0        157.0
 RUDDER ANGLE =  -10.00000

    850.0     15.71       1.76       15.81       -392.02      3241.09      371.2       1.7        156.7
    860.0     15.53       1.95       15.66       -313.17      3259.09      360.7       2.2        156.0
    870.0     15.32       2.05       15.46       -233.32      3262.71      349.5       2.4        155.2
    880.0     15.11       2.09       15.26       -155.28      3251.20      338.1       2.5        154.4
    890.0     14.92       2.10       15.07        -81.98      3224.94      326.6       2.5        153.6
    900.0     14.75       2.09       14.90        -16.12      3185.18      315.1       2.4        153.0
    910.0     14.60       2.08       14.75         39.98      3133.73      303.7       2.4        152.4
    920.0     14.47       2.06       14.62         84.45      3072.83      292.4       2.3        151.9
    930.0     14.37       2.05       14.51        115.91      3004.97      281.1       2.3        151.5
    940.0     14.27       2.04       14.42        133.48      2932.79      270.0       2.3        151.1
    950.0     14.20       2.03       14.34        136.78      2859.01      258.9       2.2        150.8
    960.0     14.13       2.02       14.28        125.91      2786.33      247.9       2.2        150.6
    970.0     14.08       2.01       14.22        101.48      2717.38      236.9       2.2        150.4
 RUDD[illegible]ANGL[illegible] -15[illegible]00
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    980.0    13.98    2.10    14.13      64.61    2654.49   225.7    2.0    150.1
    990.0    13.79    2.23    13.97      16.79    2600.43   213.4    2.3    149.4
   1000.0    13.59    2.28    13.78     -40.50    2558.11   200.7    2.4    148.6
   1010.0    13.40    2.29    13.59    -104.70    2529.62   187.9    2.4    147.9
   1020.0    13.23    2.28    13.42    -172.70    2516.06   175.2    2.4    147.3
   1030.0    13.08    2.27    13.28    -241.22    2517.68   162.5    2.4    146.7
   1040.0    12.96    2.25    13.16    -307.08    2534.01   150.0    2.3    146.3
   1050.0    12.86    2.23    13.05    -367.33    2563.93   137.5    2.3    145.9
   1060.0    12.77    2.22    12.97    -419.37    2605.80   125.1    2.2    145.6
   1070.0    12.70    2.21    12.89    -461.00    2657.50   112.8    2.2    145.3
   1080.0    12.64    2.20    12.83    -490.55    2716.55   100.6    2.2    145.1
   1090.0    12.59    2.19    12.78    -506.86    2780.24    88.4    2.2    144.9
 RUDDER ANGLE =  -10.00000

   1100.0    12.55    2.18    12.74    -509.38    2845.70    76.3    2.2    144.7
   1110.0    12.62    2.03    12.78    -497.96    2910.17    64.9    2.0    144.9
   1120.0    12.73    1.94    12.88    -473.76    2971.45    54.3    1.9    145.3
   1130.0    12.86    1.90    13.00    -438.23    3027.61    44.0    1.9    145.8
   1140.0    12.98    1.88    13.11    -392.70    3076.85    33.8    1.9    146.2
   1150.0    13.09    1.88    13.22    -338.63    3117.49    23.6    1.9    146.6
   1160.0    13.18    1.89    13.32    -277.70    3148.08    13.4    1.9    147.0
   1170.0    13.27    1.89    13.40    -211.84    3167.42     3.1    1.9    147.3
   1180.0    13.34    1.90    13.48    -143.17    3174.70    -7.2    2.0    147.6
   1190.0    13.41    1.91    13.54     -73.95    3169.50   -17.6    2.0    147.8
   1200.0    13.46    1.92    13.60      -6.51    3151.80   -28.0    2.0    148.0
   1210.0    13.51    1.92    13.65      56.84    3122.06   -38.5    2.0    148.2
   1220.0    13.55    1.93    13.69     113.92    3081.17   -49.0    2.0    148.4
 RUDDER ANGLE =  -5.000000

   1230.0    13.60    1.89    13.73     162.70    3030.41   -59.4    2.2    148.5
   1240.0    13.73    1.72    13.83     201.54    2971.25   -68.8    1.9    148.9
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   1250.0    13.89     1.62     13.98      230.30    2905.82    -77.4     1.8     149.6
   1260.0    14.06     1.56     14.15      248.94    2835.97    -85.6     1.7     150.2
   1270.0    14.23     1.53     14.31      257.33    2763.31    -93.6     1.7     150.8
   1280.0    14.38     1.52     14.46      255.32    2689.38   -101.6     1.6     151.4
   1290.0    14.52     1.52     14.60      242.86    2615.72   -109.6     1.6     152.0
   1300.0    14.65     1.52     14.73      220.05    2543.85   -117.5     1.7     152.5
   1310.0    14.76     1.52     14.84      187.18    2475.32   -125.5     1.7     152.9
   1320.0    14.86     1.53     14.94      144.76    2411.60   -133.6     1.7     153.3
   1330.0    14.95     1.54     15.03       93.50    2354.10   -141.6     1.7     153.6
   1340.0    15.02     1.55     15.10       34.32    2304.15   -149.8     1.7     153.9
   1350.0    15.09     1.55     15.17      -31.64    2262.89   -157.9     1.8     154.2
   1360.0    15.15     1.56     15.23     -103.09    2231.32   -166.1     1.8     154.4
 RUDDER ANGLE =  0.0000000E+00

   1370.0    15.24     1.37     15.30     -178.64    2210.33   -173.6     1.6     154.7
   1380.0    15.39     1.17     15.43     -256.85    2199.34   -179.6     1.3     155.3
   1390.0    15.56     1.02     15.59     -336.56    2196.81   -184.7     1.2     155.9
   1400.0    15.74     0.91     15.76     -417.05    2201.64   -189.1     1.1     156.6
   1410.0    15.91     0.82     15.93     -497.77    2213.03   -193.1     1.0     157.3
   1420.0    16.08     0.75     16.10     -578.31    2230.36   -196.7     0.9     158.0
   1430.0    16.24     0.69     16.25     -658.36    2253.09   -200.0     0.8     158.6
   1440.0    16.39     0.64     16.40     -737.65    2280.79   -203.1     0.8     159.2
   1450.0    16.52     0.61     16.53     -815.96    2313.09   -206.0     0.7     159.7
   1460.0    16.65     0.57     16.66     -893.10    2349.65   -208.7     0.7     160.2
   1470.0    16.76     0.54     16.77     -968.93    2390.19   -211.3     0.6     160.7
   1480.0    16.87     0.52     16.87    -1043.30    2434.43   -213.8     0.6     161.1
   1490.0    16.96     0.50     16.97    -1116.11    2482.13   -216.1     0.6     161.5
   1500.0    17.05     0.48     17.05    -1187.25    2533.08   -218.4     0.6     161.8
   1510.0    17.12     0.46     17.13    -1256.64    2587.06   -220.5     0.5     162.2
       0      7.1               7.2         024.        3.8         6              16
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    1530.0    17.25     0.43    17.26     -1389.89    2703.40    -224.6     0.5     162.7
    1540.0    17.31     0.42    17.32     -1453.64    2765.42    -226.6     0.5     162.9
    1550.0    17.36     0.41    17.37     -1515.39    2829.80    -228.5     0.5     163.1
    1560.0    17.41     0.40    17.41     -1575.12    2896.40    -230.4     0.5     163.3
    1570.0    17.45     0.39    17.45     -1632.79    2965.08    -232.2     0.5     163.5
    1580.0    17.49     0.38    17.49     -1688.38    3035.71    -233.9     0.4     163.6
    1590.0    17.52     0.37    17.52     -1741.86    3108.17    -235.7     0.4     163.8
    1600.0    17.55     0.36    17.55     -1793.21    3182.36    -237.3     0.4     163.9
    1610.0    17.58     0.36    17.58     -1842.41    3258.16    -239.0     0.4     164.0
    1620.0    17.60     0.35    17.60     -1889.46    3335.47    -240.6     0.4     164.1
RUDDER ANGLE =   5.C00000

    1630.0    17.61     0.17    17.61     -1934.24    3414.22    -241.8     0.7     164.2
    1640.0    17.61    -0.29    17.62     -1977.44    3493.88    -240.5     0.0     164.2
    1650.0    17.58    -0.74    17.60     -2022.09    3572.70    -236.8    -0.7     164.1
    1660.0    17.50    -1.10    17.53     -2071.11    3648.62    -231.2    -1.2     163.7
    1670.0    17.36    -1.36    17.41     -2126.60    3719.30    -224.2    -1.6     163.2
    1680.0    17.19    -1.53    17.26     -2189.50    3782.44    -216.3    -1.9     162.5
    1690.0    17.00    -1.63    17.08     -2259.68    3835.93    -207.7    -2.0     161.8
    1700.0    16.81    -1.68    16.90     -2336.11    3878.11    -198.8    -2.1     161.0
    1710.0    16.63    -1.70    16.72     -2417.23    3907.81    -189.8    -2.1     160.3
    1720.0    16.47    -1.71    16.56     -2501.13    3924.34    -180.7    -2.1     159.7
    1730.0    16.33    -1.71    16.42     -2585.81    3927.46    -171.6    -2.1     159.1
    1740.0    16.20    -1.71    16.29     -2669.25    3917.31    -162.5    -2.1     158.6
    1750.0    16.09    -1.70    16.18     -2749.47    3894.36    -153.5    -2.1     158.1
    1760.0    16.00    -1.69    16.09     -2824.65    3859.39    -144.5    -2.1     157.8
    1770.0    15.92    -1.68    16.01     -2893.11    3813.41    -135.6    -2.0     157.4
    1780.0    15.85    -1.67    15.94     -2953.36    3757.67    -126.8    -2.0     157.2
    1790.0    15.79    -1.67    15.88     -3004.10    3693.58    -117.9    -2.0     156.9
RUDDER ANGLE =  10.00000
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  1800.0     15.74     -1.66     15.82     -3044.29     3622.73     -109.1     -2.0     156.7
  1810.0     15.58     -1.89     15.70     -3073.14     3547.01      -99.3     -2.3     156.2
  1820.0     15.37     -2.04     15.51     -3088.55     3468.33      -88.2     -2.4     155.4
  1830.0     15.15     -2.10     15.30     -3088.86     3389.21      -76.7     -2.5     154.5
  1840.0     14.95     -2.12     15.09     -3073.80     3312.64      -65.0     -2.5     153.7
  1850.0     14.76     -2.12     14.91     -3044.14     3241.54      -53.4     -2.4     153.0
  1860.0     14.59     -2.11     14.75     -3001.35     3178.56      -41.8     -2.4     152.4
  1870.0     14.45     -2.09     14.61     -2947.42     3125.92      -30.3     -2.4     151.8
  1880.0     14.34     -2.08     14.49     -2884.69     3085.38      -18.9     -2.3     151.4
  1890.0     14.23     -2.06     14.38     -2815.73     3058.17       -7.6     -2.3     151.0
  1900.0     14.15     -2.05     14.30     -2743.27     3045.05        3.6     -2.3     150.7
  1910.0     14.08     -2.04     14.22     -2670.04     3046.26       14.8     -2.2     150.4
  1920.0     14.02     -2.03     14.16     -2598.76     3061.53       25.9     -2.2     150.1
RUDDER ANGLE =    15.00000

  1930.0     13.96     -2.02     14.11     -2532.02     3090.11       37.0     -2.2     149.9
  1940.0     13.79     -2.20     13.97     -2472.30     3130.58       48.9     -2.4     149.4
  1950.0     13.58     -2.28     13.77     -2422.72     3181.71       61.6     -2.4     148.6
  1960.0     13.38     -2.31     13.58     -2385.92     3241.50       74.6     -2.4     147.8
  1970.0     13.20     -2.31     13.40     -2363.56     3307.02       87.5     -2.4     147.2
  1980.0     13.04     -2.29     13.24     -2356.37     3374.99.     100.3     -2.4     146.6
  1990.0     12.90     -2.28     13.10     -2364.25     3442.13      113.1     -2.3     146.0
  2000.0     12.79     -2.26     12.98     -2386.46     3505.29      125.7     -2.3     145.6
  2010.0     12.69     -2.25     12.89     -2421.59     3561.64      138.3     -2.3     145.3
  2020.0     12.61     -2.23     12.81     -2467.77     3608.73      150.7     -2.2     145.0
  2030.0     12.54     -2.22     12.74     -2522.67     3644.57      163.1     -2.2     144.7
  2040.0     12.48     -2.21     12.68     -2583.68     3667.70      175.5     -2.2     144.5
  2050.0     12.44     -2.21     12.63     -2647.95     3677.25      187.8     -2.2     144.3
RUDDER ANGLE =    20.00000

END OF SPIRAL TEST
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                         RESULTS FROM TIME SIMULATION ANALYSIS
                                   SPIRAL MANOEUVRE
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               DESCRIPTION                               VALUE                  UNITS
_________________________________________________________________________________________
 THE RESULTS FOR THE SPIRAL TEST ARE SUMMARIZED BELOW.  THEY ARE THE
 CONSTANT RATES OF TURN AT EACH RUDDER ANGLE, STARTING WITH THE INITIAL
 ANGLE, AND SUBSEQUENTLY CHANGING BY "DELTANG".
 THE INITIAL RUDDER ANGLE IS                             15.00                  DEGREES
 THE CHANGE OF RUDDER ANGLE IS                            5.00                  DEGREES
  THE ANGLE IS =  15.0
THE CONSTANT YAW RATE IS                                0.127E+01              DEG./SEC.
  THE ANGLE IS =  10.0
THE CONSTANT YAW RATE IS                                0.107E+01              DEG./SEC.
  THE ANGLE IS =   5.0
THE CONSTANT YAW RATE IS                                0.832E+00              DEG./SEC.
  THE ANGLE IS =   0.0
THE CONSTANT YAW RATE IS                                0.160E+00              DEG./SEC.
  THE ANGLE IS =  -5.0
THE CONSTANT YAW RATE IS                               -0.868E+00              DEG./SEC.
  THE ANGLE IS = -10.0
THE CONSTANT YAW RATE IS                               -0.109E+01              DEG./SEC.
  THE ANGLE IS = -15.0
THE CONSTANT YAW RATE IS                               -0.121E+01              DEG./SEC.
  THE ANGLE IS = -10.0
THE CONSTANT YAW RATE IS                               -0.105E+01              DEG./SEC.
  THE ANGLE IS =  -5.0
THE CONSTANT YAW RATE IS                               -0.823E+00              DEG./SEC.
  THE ANGLE IS =   0.0
THE CONSTANT YAW RATE IS                               -0.160E+00              DEG./SEC.
  THE ANGLE IS =   5.0
THE CONSTANT YAW RATE IS                                0.877E+00              DEG./SEC.
  THE ANGLE IS =  10.0
THE CONSTANT YAW RATE IS                                0.111E+01              DEG./SEC.
  THE ANGLE IS =  15.0
THE CONSTANT YAW RATE IS                                0.123E+01              DEG./SEC.
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                            RESULTS FROM THE EMPIRICAL ANALYSIS

                                  CRASH STOP MANOEUVRE
****************************************************************************************************
                DESCRIPTION                                  VALUE                UNITS
____________________________________________________________________________________________________
INITIAL SPEED OF SHIP                                        18.99                KNOTS
INITIAL RESISTANCE OF SHIP                                  666.5                  KN
MAXIMUM ASTERN THRUST                                       571.2                  KN
NON-DIMENSIONAL HEAD REACH (REACH/LPP)                        4.48                -----
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```
EEEEEEEEEE   99999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999   EEEEEEEEEE
EEEEEEEEEE   9999999999999999999999999  Digital Equipment Corporation - VAX/VMS Version V4.6  9999999999999999999999999   EEEEEEEEEE
EEEEEEEEEE   99999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999   EEEEEEEEEE

                                  L       AAA   N   N  TTTTT   OOO   SSSS
                                  L      A   A  N   N    T    O   O S
                                  L      A   A  NN  N    T    O   O S
                                  L      A   A  N N N    T    O   O  SSS
                                  L      AAAAA  N  NN    T    O   O     S
                                  L      A   A  N   N    T    O   O     S
                                  LLLLL  A   A  N   N    T     OOO  SSSS

                FFFFFFFFFF  RRRRRRRR    TTTTTTTTTT    222222      000000    ZZZZZZZZZZ    IIIIII      GGGGGGGG
                FFFFFFFFFF  RRRRRRRR    TTTTTTTTTT    222222      000000    ZZZZZZZZZZ    IIIIII      GGGGGGGG
                FF          RR      RR      TT      22      22  00      00          ZZ      II      GG
                FF          RR      RR      TT      22      22  00      00          ZZ      II      GG
                FF          RR      RR      TT              22  00    0000        ZZ        II      GG
                FF          RR      RR      TT              22  00    0000        ZZ        II      GG
                FFFFFFFF    RRRRRRRR        TT            22    00  00  00      ZZ          II      GG
                FFFFFFFF    RRRRRRRR        TT            22    00  00  00      ZZ          II      GG
                FF          RR  RR          TT          22      0000    00    ZZ            II      GG    GGGGGG
                FF          RR  RR          TT          22      0000    00    ZZ            II      GG    GGGGGG
                FF          RR    RR        TT        22        00      00  ZZ              II      GG        GG
                FF          RR    RR        TT        22        00      00  ZZ              II      GG        GG
                FF          RR      RR      TT      2222222222    000000    ZZZZZZZZZZ    IIIIII      GGGGGG
                FF          RR      RR      TT      2222222222    000000    ZZZZZZZZZZ    IIIIII      GGGGGG

                                  DDDDDDDD      AAAAAA    TTTTTTTTTT      ;;;;        11
                                  DDDDDDDD      AAAAAA    TTTTTTTTTT      ;;;;        11
                                  DD      DD  AA      AA      TT          ;;;;      1111
                                  DD      DD  AA      AA      TT          ;;;;      1111
                                  DD      DD  AA      AA      TT                      11
                                  DD      DD  AA      AA      TT                      11
                                  DD      DD  AA      AA      TT          ;;;;        11
                                  DD      DD  AA      AA      TT          ;;;;        11
                                  DD      DD  AAAAAAAAAA      TT          ;;;;        11
                                  DD      DD  AAAAAAAAAA      TT          ;;;;        11
                          ....    DD      DD  AA      AA      TT            ;;        11
                          ....    DD      DD  AA      AA      TT            ;;        11
                          ....    DDDDDDDD    AA      AA      TT          ;;        111111
                          ....    DDDDDDDD    AA      AA      TT          ;;        111111

File _DUA1:[LANTOS]FRT20ZIG.DAT;1 (1075,131,0), last revised on 28-SEP-1988 10:12, is a 1 block sequential file owned by UIC
[QANDM,LANTOS].  The records are variable length with implied (CR) carriage control.  The longest record is 57 bytes.

Job ALG08-158PIR (221) queued to SYS$PRINT on 28-SEP-1988 10:14 by user LANTOS, UIC [QANDM,LANTOS], under account QANDM at priority
100, started on printer _TXA3: on 28-SEP-1988 10:27 from queue SYS$PRINT.

EEEEEEEEEE   99999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999   EEEEEEEEEE
EEEEEEEEEE   9999999999999999999999999  Digital Equipment Corporation - VAX/VMS Version V4.6  9999999999999999999999999   EEEEEEEEEE
EEEEEEEEEE   99999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999   EEEEEEEEEE
```

```
1025. , 1. 1889E-6, 1, 9. 4, 5. 712E5
137. , 137. , 19. 9, 6. 1, 4. 4, . 64, . 88, . 85, 9. 246E6
2. 33, -11. 04, 0. , 0. , 9. 77, 0. , 0. , 0. , 2. 83, 0. , 0. , 0. , 0. , 0.
0. 15, 0. , -69. , 4. 2, 0. 15, 11. 4, 5. 69, 1. 55, 5. 19, 8. 25, 0. , 11, 150.
0. , 0, 1, 0. , 0. , 8. , 3. , 1
45. 6, 1. 4
2, 4000. , 1. , 20. , 14, 4. 05, 1. , . 8, 4, 9. 888E6, 2, -68. , 7. 3
9. 77, 2, 1, 8. , 2. , 0, 5.
```

,34

```
HHHHHHHHHH     0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000     HHHHHHHHHH
HHHHHHHHHH     0000000000000000000000000  Digital Equipment Corporation - VAX/VMS Version V4.6  0000000000000000000000000     HHHHHHHHHH
HHHHHHHHHH     0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000     HHHHHHHHHH

                                   L       AAA   N   N  TTTTT   OOO    SSSS
                                   L      A   A  N   N    T    O   O  S
                                   L      A   A  NN  N    T    O   O  S
                                   L      A   A  N N N    T    O   O   SSS
                                   L      AAAAA  N  NN    T    O   O      S
                                   L      A   A  N   N    T    O   O      S
                                   LLLLL  A   A  N   N    T     OOO   SSSS

                             SSSSSSSS     IIIIII    MM      MM  UU      UU  LL
                             SSSSSSSS     IIIIII    MM      MM  UU      UU  LL
                            SS              II      MMMM  MMMM  UU      UU  LL
                            SS              II      MMMM  MMMM  UU      UU  LL
                            SS              II      MM  MM  MM  UU      UU  LL
                            SS              II      MM  MM  MM  UU      UU  LL
                             SSSSSS         II      MM      MM  UU      UU  LL
                             SSSSSS         II      MM      MM  UU      UU  LL
                                   SS       II      MM      MM  UU      UU  LL
                                   SS       II      MM      MM  UU      UU  LL
                                   SS       II      MM      MM  UU      UU  LL
                                   SS       II      MM      MM  UU      UU  LL
                            SSSSSSSS      IIIIII    MM      MM  UUUUUUUUUU  LLLLLLLLLL
                            SSSSSSSS      IIIIII    MM      MM  UUUUUUUUUU  LLLLLLLLLL

                              OOOOOO    UU      UU  TTTTTTTTTT      ;;;;        11      5555555555
                              OOOOOO    UU      UU  TTTTTTTTTT      ;;;;        11      5555555555
                            OO      OO  UU      UU      TT          ;;;;      1111      55
                            OO      OO  UU      UU      TT          ;;;;      1111      55
                            OO      OO  UU      UU      TT                      11      555555
                            OO      OO  UU      UU      TT                      11      555555
                            OO      OO  UU      UU      TT          ;;;;        11            55
                            OO      OO  UU      UU      TT          ;;;;        11            55
                            OO      OO  UU      UU      TT          ;;;;        11              55
                            OO      OO  UU      UU      TT          ;;;;        11              55
                    ....    OO      OO  UU      UU      TT            ;;        11      55      55
                    ....    OO      OO  UU      UU      TT            ;;        11      55      55
                    ....      OOOOOO    UUUUUUUUUU      TT          ;;        111111      555555
                    ....      OOOOOO    UUUUUUUUUU      TT          ;;        111111      555555

File _DUA1:[LANTOS]SIMUL.OUT;15 (903,52,0), last revised on 28-SEP-1988 10:48, is a 22 block sequential file owned by UIC
[QANDM,LANTOS].  The records are variable length with FORTRAN (FTN) carriage control.  The longest record is 116 bytes.

Job SIMUL (226) queued to SYS$PRINT on 28-SEP-1988 10:52 by user LANTOS, UIC [QANDM,LANTOS], under account QANDM at priority 100,
started on printer _TXA3: on 28-SEP-1988 10:53 from queue SYS$PRINT.

HHHHHHHHHH     0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000     HHHHHHHHHH
HHHHHHHHHH     0000000000000000000000000  Digital Equipment Corporation - VAX/VMS Version V4.6  0000000000000000000000000     HHHHHHHHHH
HHHHHHHHHH     0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000     HHHHHHHHHH
```

```
                                   INPUT DATA
                                 ZIGZAG MANOEUVRE
*****************************************************************************************
                 DESCRIPTION                              VALUE                UNITS
-----------------------------------------------------------------------------------------
LENGTH BETWEEN PERPENDICULARS                            137.00               METERS
LENGTH ON WATERLINE                                      137.00               METERS
BREADTH                                                   19.90               METERS
DRAFT AFT                                                  6.10               METERS
DRAFT FWD                                                  4.40               METERS
DISPLACEMENT                                            9246.00               TONNES
BLOCK COEFFICIENT                                          0.64               -----
MIDSHIP SECTION COEFFICIENT                                0.88               -----
WATERPLANE COEFFICIENT                                     0.85               -----
RUDDER LATERAL AREA                                       11.4                SQ. METERS
PROPELLER DIAMETER                                         4.05               METERS
PROPELLER PITCH/DIAMETER RATIO                             1.00               -----
PROPELLER EXPANDED BLADE AREA RATIO                        0.80               -----
SHAFT HORSEPOWER                                        9888.0                 KW
*****************************************************************************************
                           SHIP SPEED - POWER DATA
SPEED      WAVE       APPEND     BULB BOW    TRANSOM      CORR.     FRICTION     TOTAL      EFFECTIVE
(KNOTS)   RESIST      RESIST      RESIST      RESIST     RESIST      RESIST      RESIST    HORSEPOWER
           (KN)        (KN)        (KN)        (KN)        (KN)        (KN)        (KN)        (KW)
*****************************************************************************************
 14.0   0.389E+02   0.266E+01   0.364E+02   0.000E+00   0.381E+02   0.129E+03   0.285E+03   0.205E+04
 15.0   0.624E+02   0.303E+01   0.381E+02   0.000E+00   0.437E+02   0.147E+03   0.340E+03   0.262E+04
 16.0   0.953E+02   0.342E+01   0.395E+02   0.000E+00   0.497E+02   0.166E+03   0.405E+03   0.334E+04
 17.0   0.139E+03   0.383E+01   0.408E+02   0.000E+00   0.562E+02   0.186E+03   0.484E+03   0.423E+04
 18.0   0.188E+03   0.426E+01   0.420E+02   0.000E+00   0.630E+02   0.207E+03   0.568E+03   0.526E+04
 19.0   0.249E+03   0.471E+01   0.431E+02   0.000E+00   0.701E+02   [illegible] [illegible] [illegible]
 [illegible] [illegible] [illegible] [illegible] 0.000E+00 0.777E+02 0.252E+03 0.803E+03  0.827E+04
```

```
    21.0    0.478E+03   0.569E+01   0.448E+02   0.000E+00   0.857E+02   0.276E+03   0.977E+03    0.106E+05
    22.0    0.608E+03   0.621E+01   0.456E+02   0.000E+00   0.940E+02   0.301E+03   0.115E+04    0.130E+05
    23.0    0.696E+03   0.675E+01   0.463E+02   0.000E+00   0.103E+03   0.328E+03   0.128E+04    0.152E+05
    24.0    0.746E+03   0.731E+01   0.469E+02   0.000E+00   0.112E+03   0.355E+03   0.138E+04    0.170E+05
   WAKE FRACTION =  0.150
   THRUST DEDUCTION FRACTION =  0.195
   FORM FACTOR OF THE HULL =  0.312
   The friction resistance in the above table was
   multiplied by (1.+CFORM) to obtain the total
   resistance.
   ***********************************************************************************************************
     TIME       LOCAL       LOCAL        LOCAL          GLOBAL         GLOBAL       YAW ANGLE   ROLL ANGLE   PROPELLER
               X-SPEED     Y-SPEED    SHIP SPEED     X-POSITION     Y-POSITION                                SPEED
    (SECS)     (KNOTS)     (KNOTS)     (KNOTS)        (METERS)       (METERS)     (DEGREES)    (DEGREES)      (RPM)
   ***********************************************************************************************************
       0.0      18.99        0.00       18.99           0.00           0.00          0.0          0.0        169.8
      10.0      18.65       -0.84       18.67          97.10          -0.36          2.4          0.2        168.7
      20.0      17.86       -2.16       17.99         191.36           3.63         13.3         -2.3        165.6
      30.0      16.96       -2.60       17.16         279.30          23.38         28.6         -4.2        161.9
      40.0      16.48       -1.68       16.57         356.05          63.13         40.0         -3.4        159.7
  RUDDER ANGLE IS  -20.00000

      50.0      16.24       -0.26       16.24         422.12         115.24         41.8         -1.2        158.8
      60.0      16.02        1.17       16.07         484.98         169.62         35.4          0.6        158.1
      70.0      15.58        2.12       15.72         551.11         217.76         23.8          2.2        156.4
      80.0      14.97        2.55       15.19         622.74         252.02.         9.4          2.9        154.1
      90.0      14.34        2.67       14.59         697.47         267.86         -5.9          3.1        151.7
     100.0      13.77        2.52       13.99         770.78         264.30        -21.2          3.4        149.5
     110.0      13.65        1.97       13.79         838.51         242.40        -33.1          3.5        148.7
  RUDDER ANGLE IS   20.00000

     120.0      13.70        0.79       13.72         899.37         206.63        -38.0          1.8        148.9
     130.0      13.84       -0.49       13.85         956.53         164.70        -34.7          0.3        149.6
   140.0    13.81     -1.57     13.90      1015.05     123.73    -25.7     -1.2      149.5
   150.0    13.57     -2.18     13.75      1078.02      90.69    -13.4     -2.1      148.7
   160.0    13.23     -2.43     13.45      1145.03      70.97      0.5     -2.5      147.4
   170.0    12.87     -2.51     13.11      1213.09      67.19     14.8     -2.6      146.0
   180.0    12.65     -2.33     12.87      1278.42      79.74     28.7     -3.1      145.1
RUDDER ANGLE IS  -20.00000

   190.0    12.75     -1.44     12.83      1338.07     107.79     37.8     -2.4      145.3
   200.0    12.97     -0.34     12.98      1392.30     145.84     39.1     -1.0      146.2
   210.0    13.19      0.80     13.22      1445.37     187.39     34.0      0.1      147.1
   220.0    13.22      1.67     13.32      1501.32     226.62     24.5      1.3      147.3
   230.0    13.07      2.14     13.24      1562.20     257.60     12.4      2.0      146.7
   240.0    12.82      2.35     13.04      1627.16     275.91     -0.9      2.3      145.8
   250.0    12.56      2.42     12.80      1693.37     279.30    -14.6      2.4      144.9
   260.0    12.44      2.15     12.63      1757.31     267.22    -27.4      2.1      144.3
RUDDER ANGLE IS   20.00000

   270.0    12.61      1.31     12.67      1816.67     240.83    -35.6      1.9      144.8
   280.0    12.85      0.17     12.85      1871.59     205.08    -36.0      0.8      145.8
   290.0    13.04     -1.00     13.08      1926.06     166.53    -29.9     -0.4      146.6
   300.0    13.02     -1.82     13.15      1983.79     131.53    -19.4     -1.5      146.6
   310.0    12.84     -2.23     13.03      2046.09     106.06     -6.8     -2.1      145.9
   320.0    12.58     -2.40     12.81      2111.36      94.10      6.9     -2.3      145.0
   330.0    12.33     -2.45     12.57      2176.41      97.26     20.8     -2.4      144.0
END OF ZIGZAG SIMULATION

                      RESULTS FROM TIME SIMULATION ANALYSIS
                                ZIGZAG MANOEUVRE
*************************************************************************************
                  DESCRIPTION                        VALUE                  UNITS
```

```
OVERSHOOT ANGLE                                                     22.23                DEGREES
NON-DIMENSIONAL OVERSHOOT WIDTH OF PATH (WIDTH/LPP)                  1.88                -----
PERIOD BETWEEN 1st RUDDER CHANGE AND 3rd RUDDER CHANGE             149.0                 SECS.
NON-DIMENSIONAL REACH (REACH/LPP)                                    4.93                -----
***********************************************************************************************

                              RESULTS FROM THE EMPIRICAL ANALYSIS

                                     CRASH STOP MANOEUVRE
***********************************************************************************************
                 DESCRIPTION                                        VALUE                UNITS
-----------------------------------------------------------------------------------------------
INITIAL SPEED OF SHIP                                               18.99                KNOTS
INITIAL RESISTANCE OF SHIP                                         666.5                  KN
MAXIMUM ASTERN THRUST                                              571.2                  KN
NON-DIMENSIONAL HEAD REACH (REACH/LPP)                               4.48                -----
***********************************************************************************************
```

```
FFFFFFFFFFF   9999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999    FFFFFFFFFFF
FFFFFFFFFFF   9999999999999999999999999  Digital Equipment Corporation - VAX/VMS Version V4.6  9999999999999999999999999    FFFFFFFFFFF
FFFFFFFFFFF   9999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999    FFFFFFFFFFF

                                              L       AAA   N   N  TTTTT   OOO    SSSS
                                              L      A   A  N   N    T    O   O  S
                                              L      A   A  NN  N    T    O   O  S
                                              L      A   A  N N N    T    O   O   SSS
                                              L      AAAAA  N  NN    T    O   O      S
                                              L      A   A  N   N    T    O   O      S
                                              LLLLL  A   A  N   N    T     OOO   SSSS

                   FFFFFFFFFF  RRRRRRRR    TTTTTTTTTT    333333    5555555555    CCCCCCCC  IIIIII      RRRRRRRR
                   FFFFFFFFFF  RRRRRRRR    TTTTTTTTTT    333333    5555555555    CCCCCCCC  IIIIII      RRRRRRRR
                   FF          RR      RR      TT      33      33  55          CC            II        RR      RR
                   FF          RR      RR      TT      33      33  55          CC            II        RR      RR
                   FF          RR      RR      TT              33  555555      CC            II        RR      RR
                   FF          RR      RR      TT              33  555555      CC            II        RR      RR
                   FFFFFFFF    RRRRRRRR        TT            33          55    CC            II        RRRRRRRR
                   FFFFFFFF    RRRRRRRR        TT            33          55    CC            II        RRRRRRRR
                   FF          RR  RR          TT              33          55  CC            II        RR  RR
                   FF          RR  RR          TT              33          55  CC            II        RR  RR
                   FF          RR    RR        TT      33      33  55      55  CC            II        RR    RR
                   FF          RR    RR        TT      33      33  55      55  CC            II        RR    RR
                   FF          RR      RR      TT        333333      555555      CCCCCCCC  IIIIII      RR      RR
                   FF          RR      RR      TT        333333      555555      CCCCCCCC  IIIIII      RR      RR

                                           DDDDDDDD      AAAAAA    TTTTTTTTTT      ;;;;         11
                                           DDDDDDDD      AAAAAA    TTTTTTTTTT      ;;;;         11
                                           DD      DD  AA      AA      TT          ;;;;       1111
                                           DD      DD  AA      AA      TT          ;;;;       1111
                                           DD      DD  AA      AA      TT                       11
                                           DD      DD  AA      AA      TT                       11
                                           DD      DD  AA      AA      TT          ;;;;         11
                                           DD      DD  AA      AA      TT          ;;;;         11
                                           DD      DD  AAAAAAAAAA      TT          ;;;;         11
                                           DD      DD  AAAAAAAAAA      TT          ;;;;         11
                                   ....    DD      DD  AA      AA      TT            ;;         11
                                   ....    DD      DD  AA      AA      TT            ;;         11
                                   ....    DDDDDDDD    AA      AA      TT          ;;         111111
                                   ....    DDDDDDDD    AA      AA      TT          ;;         111111

File _DUA1:[LANTOS]FRT35CIR.DAT;1 (946,120,0), last revised on 28-SEP-1988 10:12, is a 1 block sequential file owned by UIC
[QANDM,LANTOS].  The records are variable length with implied (CR) carriage control.  The longest record is 57 bytes.

Job ALQOB-15SPIR (221) queued to SYS$PRINT on 28-SEP-1988 10:14 by user LANTOS, UIC [QANDM,LANTOS], under account QANDM at priority
100, started on printer _TXA3: on 28-SEP-1988 10:27 from queue SYS$PRINT.

FFFFFFFFFFF   9999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999    FFFFFFFFFFF
FFFFFFFFFFF   9999999999999999999999999  Digital Equipment Corporation - VAX/VMS Version V4.6  9999999999999999999999999    FFFFFFFFFFF
FFFFFFFFFFF   9999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999    FFFFFFFFFFF
```

```
1025. , 1. 1889E-6, 1, 9. 4, 5. 712E3
137. , 137. , 19. 9, 6. 1, 4. 4, . 64, . 88, . 85, 9. 246E6
2. 33, -11. 04, 0. , 0. , 9. 77, 0. , 0. , 0. , 2. 83, 0. , 0. , 0. , 0. , 0.
0. 15, 0. , -69. , 4. 2, 0. 15, 11. 4, 5. 69, 1. 55, 5. 19, 8. 25, 0. , 11, 150.
0. , 0, 1, 0. , 0. , 8. , 3. , 1
45. 6, 1. 4
1, 4000. , 1. , 35. , 14, 4. 05, 1. , . 8, 4, 9. 888E6, 2, -68. , 7. 3
9. 77, 2, 1, 8. , 2. , 0, 5.
```

```
0000000000   000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000   0000000000
0000000000   0000000000000000000000000  Digital Equipment Corporation - VAX/VMS Version V4.6  0000000000000000000000000   0000000000
0000000000   000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000   0000000000

                         L       AAA   N   N  TTTTT   OOO   SSSS
                         L      A   A  N   N    T    O   O S
                         L      A   A  NN  N    T    O   O S
                         L      A   A  N N N    T    O   O  SSS
                         L      AAAAA  N  NN    T    O   O     S
                         L      A   A  N   N    T    O   O     S
                         LLLLL  A   A  N   N    T     OOO  SSSS

                     SSSSSSSS   IIIIII   MM      MM  UU      UU  LL
                     SSSSSSSS   IIIIII   MM      MM  UU      UU  LL
                   SS             II     MMMM  MMMM  UU      UU  LL
                   SS             II     MMMM  MMMM  UU      UU  LL
                   SS             II     MM  MM  MM  UU      UU  LL
                   SS             II     MM  MM  MM  UU      UU  LL
                     SSSSSS       II     MM      MM  UU      UU  LL
                     SSSSSS       II     MM      MM  UU      UU  LL
                           SS     II     MM      MM  UU      UU  LL
                           SS     II     MM      MM  UU      UU  LL
                           SS     II     MM      MM  UU      UU  LL
                           SS     II     MM      MM  UU      UU  LL
                   SSSSSSSS     IIIIII   MM      MM  UUUUUUUUUU  LLLLLLLLLL
                   SSSSSSSS     IIIIII   MM      MM  UUUUUUUUUU  LLLLLLLLLL

                     OOOOOO    UU      UU  TTTTTTTTTT    ;;;;      11       666666
                     OOOOOO    UU      UU  TTTTTTTTTT    ;;;;      11       666666
                   OO      OO  UU      UU      TT        ;;;;    1111     66
                   OO      OO  UU      UU      TT        ;;;;    1111     66
                   OO      OO  UU      UU      TT                  11     66
                   OO      OO  UU      UU      TT                  11     66
                   OO      OO  UU      UU      TT        ;;;;      11     66666666
                   OO      OO  UU      UU      TT        ;;;;      11     66666666
                   OO      OO  UU      UU      TT        ;;;;      11     66      66
                   OO      OO  UU      UU      TT        ;;;;      11     66      66
              ..   OO      OO  UU      UU      TT          ;;      11     66      66
              ..   OO      OO  UU      UU      TT          ;;      11     66      66
              ..     OOOOOO    UUUUUUUUUU      TT        ;;      111111     666666
                     OOOOOO    UUUUUUUUUU      TT        ;;      111111     666666

File _DUA1:[LANTOS]SIMUL.OUT;16 (931,134,0), last revised on 28-SEP-1988 10:49, is a 23 block sequential file owned by UIC
[QANDM,LANTOS].  The records are variable length with FORTRAN (FTN) carriage control.  The longest record is 116 bytes.

Job SIMUL (226) queued to SYS$PRINT on 28-SEP-1988 10:52 by user LANTOS, UIC [QANDM,LANTOS], under account QANDM at priority 100,
started on printer _TXA3: on 28-SEP-1988 10:52 from queue SYS$PRINT.

0000000000   000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000   0000000000
0000000000   0000000000000000000000000  Digital Equipment Corporation - VAX/VMS Version V4.6  0000000000000000000000000   0000000000
0000000000   000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000   0000000000
```

```
                                        INPUT DATA
                                 TURNING CIRCLE MANOEUVRE
*****************************************************************************************
                      DESCRIPTION                            VALUE                UNITS
_________________________________________________________________________________________
LENGTH BETWEEN PERPENDICULARS                               137.00               METERS
LENGTH ON WATERLINE                                         137.00               METERS
BREADTH                                                      19.90               METERS
DRAFT AFT                                                     6.10               METERS
DRAFT FWD                                                     4.40               METERS
DISPLACEMENT                                               9246.00               TONNES
BLOCK COEFFICIENT                                             0.64               -----
MIDSHIP SECTION COEFFICIENT                                   0.88               -----
WATERPLANE COEFFICIENT                                        0.85               -----
RUDDER LATERAL AREA                                          11.4                SQ. METERS
PROPELLER DIAMETER                                            4.05               METERS
PROPELLER PITCH/DIAMETER RATIO                                1.00               -----
PROPELLER EXPANDED BLADE AREA RATIO                           0.80               -----
SHAFT HORSEPOWER                                           9888.0                  KW
*****************************************************************************************
                               SHIP SPEED - POWER DATA
 SPEED     WAVE        APPEND     BULB BOW     TRANSOM      CORR.     FRICTION      TOTAL      EFFECTIVE
          RESIST       RESIST      RESIST      RESIST       RESIST     RESIST       RESIST     HORSEPOWER
(KNOTS)    (KN)         (KN)        (KN)        (KN)         (KN)       (KN)         (KN)        (KW)
*****************************************************************************************
  14.0   0.389E+02   0.266E+01   0.364E+02   0.000E+00   0.381E+02   0.129E+03   0.285E+03   0.205E+04
  15.0   0.624E+02   0.303E+01   0.381E+02   0.000E+00   0.437E+02   0.147E+03   0.340E+03   0.262E+04
  16.0   0.953E+02   0.342E+01   0.395E+02   0.000E+00   0.497E+02   0.166E+03   0.405E+03   0.334E+04
  17.0   0.139E+03   0.383E+01   0.408E+02   0.000E+00   0.562E+02   0.186E+03   0.484E+03   0.423E+04
  18.0   0.188E+03   0.426E+01   0.420E+02   0.000E+00   0.630E+02   0.207E+03   0.568E+03   0.526E+04
  19.0   0.249E+03   0.471E+01   0.431E+02   0.000E+00   0.701E+02   0.229E+03   0.667E+03   0.652E+04
  20.0   0.346E+03   0.519E+01   0.440E+02   0.000E+00   0.777E+02   0.252E+03   0.803E+03   0.827E+04
```

143

```
 21.0   0.478E+03  0.569E+01  0.448E+02  0.000E+00  0.857E+02  0.276E+03  0.977E+03   0.106E+05
 22.0   0.608E+03  0.621E+01  0.456E+02  0.000E+00  0.940E+02  0.301E+03  0.115E+04   0.130E+05
 23.0   0.696E+03  0.675E+01  0.463E+02  0.000E+00  0.103E+03  0.328E+03  0.128E+04   0.152E+05
 24.0   0.746E+03  0.731E+01  0.469E+02  0.000E+00  0.112E+03  0.355E+03  0.138E+04   0.170E+05
WAKE FRACTION =  0.150

THRUST DEDUCTION FRACTION =  0.195

FORM FACTOR OF THE HULL =  0.312

The friction resistance in the above table was
multiplied by (1.+CFORM) to obtain the total
resistance.

**********************************************************************************************************
   TIME      LOCAL       LOCAL        LOCAL          GLOBAL        GLOBAL
           X-SPEED     Y-SPEED     SHIP SPEED     X-POSITION    Y-POSITION    YAW ANGLE   ROLL ANGLE   PROPELLER
  (SECS)    (KNOTS)     (KNOTS)      (KNOTS)       (METERS)      (METERS)     (DEGREES)   (DEGREES)      SPEED
                                                                                                         (RPM)
**********************************************************************************************************
    0.0     18.99        0.00        18.99          0.00          0.00          0.0          0.0        169.8
   10.0     18.64       -0.85        18.66         97.09         -0.36          2.4          0.3        168.7
   20.0     17.17       -2.61        17.37        189.98          3.28         15.2         -2.8        163.2
   30.0     15.36       -3.35        15.72        272.40         23.65         34.7         -4.2        156.1
   40.0     13.74       -3.40        14.15        337.49         63.67         55.1         -4.0        149.8
   50.0     12.45       -3.25        12.86        381.39        116.98         74.6         -3.5        144.9
   60.0     11.45       -3.07        11.85        404.20        175.93         92.8         -3.0        141.2
   70.0     10.68       -2.92        11.07        408.08        234.46        110.0         -2.7        138.4
   80.0     10.08       -2.80        10.46        395.94        288.24        126.3         -2.4        136.3
   90.0      9.60       -2.70         9.98        370.94        334.23        142.0         -2.2        134.7
  100.0      9.23       -2.62         9.59        336.23        370.42        157.2         -2.0        133.4
  110.0      8.93       -2.56         9.29        294.89        395.59        172.0         -1.9        132.4
  120.0      8.68       -2.51         9.04        249.92        409.19        186.5         -1.8        131.6
  130.0      8.49       -2.46         8.84        204.12        411.23        200.7         -1.7        130.9
  140.0      8.33       -2.43         8.68        160.10        402.27        214.8         -1.7        130.4
  150.0      8.20       -2.40         8.54        120.20        383.32        228.7         -1.6        130.0
  1[illegible]  [illegible]09  -2.[illegible]  [illegible]8.44  [illegible]6.42  3[illegible]5.81  242.4  -1.6  129.7
```

```
   170.0     8.01    -2.36     8.35       60.40    321.51    256.1    -1.5     129.4
   180.0     7.93    -2.35     8.27       43.32    282.43    269.7    -1.5     129.1
   190.0     7.88    -2.34     8.21       35.90    240.78    283.2    -1.5     129.0
   200.0     7.83    -2.33     8.17       38.34    198.81    296.6    -1.5     128.8
   210.0     7.79    -2.32     8.13       50.37    158.78    310.0    -1.5     128.7
   220.0     7.75    -2.31     8.09       71.23    122.77    323.4    -1.4     128.6
   230.0     7.73    -2.31     8.06       99.73     92.65    336.7    -1.4     128.5
   240.0     7.71    -2.30     8.04      134.28     69.96    350.0    -1.4     128.4
   250.0     7.69    -2.30     8.02      173.02     55.85    363.3    -1.4     128.4
END OF TURNING CIRCLE MANOEUVRE

                          RESULTS FROM TIME SIMULATION ANALYSIS
                               TURNING CIRCLE MANOEUVRE
*******************************************************************************************
                   DESCRIPTION                                 VALUE               UNITS
-------------------------------------------------------------------------------------------
STEADY TURNING SPEED                                            8.03               KNOTS
NON-DIMENSIONAL ADVANCE (ADVANCE/LPP)                           2.94               -----
NON-DIMENSIONAL TRANSFER (TRANSFER/LPP)                         1.24               -----
NON-DIMENSIONAL TACTICAL DIAMETER (TAC. DIA./LPP)               2.96               -----
NON-DIMENSIONAL STEADY TURNING DIAMETER (STDY. DIA./LPP)        2.53               -----
*******************************************************************************************

                          RESULTS FROM THE EMPIRICAL ANALYSIS
                               TURNING CIRCLE MANOEUVRE
*******************************************************************************************
                   DESCRIPTION                                 VALUE               UNITS
-------------------------------------------------------------------------------------------
STEADY TURNING SPEED                                           12.19               KNOTS
NON-DIMENSIONAL ADVANCE (ADVANCE/LPP)                           2.91               -----
NON-DIMENSIONAL TRANSFER (TRANSFER/LPP)                         1.51               -----
```

```
NON-DIMENSIONAL TACTICAL DIAMETER (TAC. DIA./LPP)                      3.52               -----
NON-DIMENSIONAL STEADY TURNING DIAMETER (STDY. DIA./LPP)               3.38               -----
STANDARD DEVIATION OF (VST/VX1) = 0.166
STANDARD DEVIATION OF (ADV/LPP) = 0.188
STANDARD DEVIATION OF (TR/LPP) = 0.129
STANDARD DEVIATION OF (TACDIA/LPP) = 0.066
STANDARD DEVIATION OF (STDYDIA/LPP) = 0.271
MESSAGES FOR EMPIRICAL TURNING CIRCLE ANALYSIS
-------------------------------------------------
BLOCK COEFFICIENT IS OUTSIDE THE RANGE OF (.42 <= CB <= .62)
RATIO (ASUB/(LPP*T)) IS OUTSIDE THE RANGE OF (-.1 <= RATIO <= 0.0)
**********************************************************************************************

                                    CRASH STOP MANOEUVRE
**********************************************************************************************
                      DESCRIPTION                                      VALUE              UNITS
----------------------------------------------------------------------------------------------
INITIAL SPEED OF SHIP                                                  18.99              KNOTS
INITIAL RESISTANCE OF SHIP                                            666.5                KN
MAXIMUM ASTERN THRUST                                                 571.2                KN
NON-DIMENSIONAL HEAD REACH (REACH/LPP)                                  4.48              -----
**********************************************************************************************
```

APPENDIX E

SEA TRIALS PROGRAM

TRIAL CATEGORY: OPEN WATER PERFORMANCE

SHEET #1

TRIAL NAME: TURNING CIRCLE MANOEUVRE

TRIAL OBJECTIVE:

To determine the effectiveness of the rudder to produce steady-state turning characteristics.

EQUIPMENT REQUIRED/PREPARATIONS FOR RECORDING DATA:

Microwave positioning system.
Yaw Gyro.

Three remote stations, consisting of microwave transponders shall be installed ashore and the distances between them measured. The master station shall be installed on the highest possible spot of the ship.

The ship's doppler speed log may be used to determine the ship's track providing sea conditions are good, a "bottom lock" is achieved and the accuracy requirements of ≤ 10m or one ship breadth are met. However, the ship's doppler speed log should only be used to support the microwave position system readings.

ENVIRONMENTAL CONDITIONS REQUIRED:

SEA: ≤ Sea State 3

CURRENT: Constant, < 1 m/s

WIND SPEED: ≤ Beaufort 4

VESSEL APPROACH SPEED: See note 1 of procedure

WATER DEPTH REQ'D >: ______

WATER DEPTH REQ'D, $D = \frac{5.522HV}{\sqrt{L_{PP}}}$

WHERE D=Minimum depth (m)
H=Trial draft (m)
V=Approach speed (knots)
Lpp=Length between perpendiculars (m)

TRIAL CATEGORY : OPEN WATER PERFORMANCE

SHEET #2

TRIAL NAME : TURNING CIRCLE MANOEUVRE

PROCEDURE :

To be performed for both the loaded and ballast operating conditions, as well as to both port and starboard.

1. Hold ship steady on a constant heading at a specified approach speed (1) for approximately one (1) minute. Once approach speed is "steadied", propulsion controls are not to be manipulated for duration of manoeuvre.
2. Record relevant data in section A of datasheet. Commencing one (1) minute before "Rudder Hardover" command, record ship's heading and position at 10 second intervals throughout the manoeuvre in the respective datasheets.
3. Move rudder hardover to starboard (2) and hold until the ship's heading has changed by 540°.
4. Resume a straight course and restore speed.
5. Repeat step 3, moving rudder hardover to port.

NOTES :

1. The throttle setting for a single screw vessel should not be changed during the manoeuvre, however, for multi-screw ships, the throttle may be adjusted as necessary to correct unacceptable overspeed or overtorque. If a throttle adjustment is required during the turn, the manoeuvre should be repeated at a reduced approach speed at which a hard turn can be made without throttle adjustment.
2. Maximum rudder angle is to be applied.

TRIAL CATEGORY: OPEN WATER PERFORMANCE

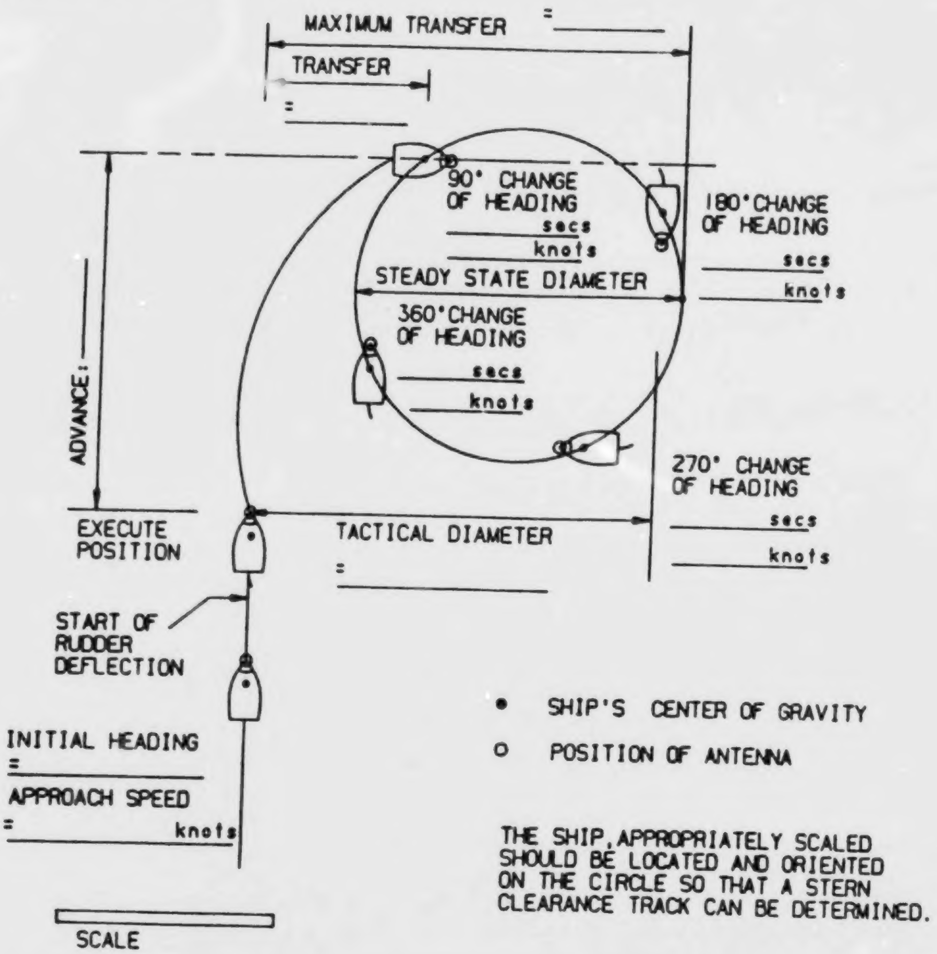
SHEET #3

TRIAL NAME: TURNING CIRCLE MANOEUVRE

RESULTS:

The ship's heading versus time is to be plotted for all engine settings listed on the datasheets. If a land-based recording system is used, the plot must be corrected for drift (Ref. App. A). The plot should be for starboard turns only, unless there is significant difference for port turns.

PRESENTATION OF RESULTS:



THE SHIP, APPROPRIATELY SCALED SHOULD BE LOCATED AND ORIENTED ON THE CIRCLE SO THAT A STERN CLEARANCE TRACK CAN BE DETERMINED.

THE TURNING CIRCLE MANOEUVRE

SHIP OPERATING CONDITION: ____________

DRAFT AFT: ______ DRAFT FWD: ____________

TRIAL CATEGORY: OPEN WATER PERFORMANCE

SHEET #4

TRIAL NAME : TURNING CIRCLE MANOEUVRE

RESULTS:

SHIP'S NAME : ____________________

TRIAL LOCATION: ____________________

ITEM		ENGINE SETTING: Full Speed Ahead, Constant Engine Setting											
		LOADED						BALLAST					
		PORT			STARBOARD			PORT			STARBOARD		
INITIAL SHAFT RPM													
INITIAL SPEED, KNOTS													
INITIAL HEADING													
RUDDER ANGLE													
WIND DIRECTION													
WIND FORCE													
SEA STATE													
ELAPSED TIME AND SHIP SPEED FOR THE VESSEL TO TURN, deg.		min	sec	kts	min	sec	kts	min	sec	kts	min	sec	kts
	10												
	20												
	90												
	180												
	270												
	360												
	450												
	540												
ADVANCE													
MAX'M. ADVANCE													
TRANSFER													
MAX'M. TRANSFER													
TACTICAL DIAMETER													
STEADY-STATE DIAMETER													
FINAL SPEED													
FINAL RPM													
DRIFT CORRECTION DIRECTION													
RATE (kts)													

SHEET #5

MANOEUVRE : ____________________
SHIP'S OPERATING CONDITION : ____________________
ENGINE SETTING: ____________________

IT SHOULD BE NOTED THAT THE RESPONSE OF THE VESSEL MAY BE DIFFRENT FROM THAT SHOWN IF ANY OF THE FOLLOWING CONDITIONS UPON WHICH THE MANOEUVRING DATA IS BASED, ARE ALTERED:

1. CALM WEATHER ≤ SEA STATE 3
2. WIND ≤ BEAUFORT 4
3. DRAFTS AS SHOWN
4. DEEP WATER CONDITION
5. CONSTANT CURRENT <1 M/S
6. CLEAN HULL

TRIAL CATEGORY: OPEN WATER PERFORMANCE

SHEET #6

TRIAL NAME: TURNING CIRCLE MANOEUVRE

CONDUCTING AUTHORITY:

OWNER'S REPRESENTATIVE:

PERFORMED BY:

AUTHORIZED BY:

SHIP MASTER:

A DATA:

SHIP NAME: ______ TEST DATE: ______

SHIP'S OPERATING CONDITION: ______

DEPTH OF WATER: ______ SEA CONDITION: ______

WIND VELOCITY: ______ WIND DIRECTION: ______

DRAFT AFT.: ______ DRAFT FWD.: ______

TRIM: ______

TRIAL LOCATION: ______

ITEM	PORT	STARBOARD
TIME TEST BEGAN		
TIME TEST ENDED		
SHIP'S HEADING		
INITIAL RUDDER ANGLE		
INITIAL SHAFT RPM.		
APPROACH SPEED		
CONTROLLABLE PITCH SETTING (IF APPL.)		

EQUIPMENT USED: (ie.Manufacturer,Model no.,Serial no.)

TRIAL CATEGORY : OPEN WATER PERFORMANCE

SHEET #7

TRIAL NAME : TURNING CIRCLE MANOEUVRE

CONDUCTING AUTHORITY :

OWNER'S REPRESENTATIVE :

PERFORMED BY :

AUTHORIZED BY :

SHIP MASTER :

B DATA:

SHIP'S OPERATING CONDITION : ____________________

ENGINE SETTING: ____________________

PORT			STARBOARD		
TIME (sec.)	HEADING (deg.)	RATE OF TURN (deg./sec.)	TIME (sec.)	HEADING (deg.)	RATE OF TURN (deg./sec.)

FINAL SPEED		FINAL SPEED	
FINAL RPM		FINAL RPM	

TRIAL CATEGORY:	OPEN WATER PERFORMANCE

SHEET #8

TRIAL NAME :	TURNING CIRCLE MANOEUVRE

CONDUCTING AUTHORITY :	PERFORMED BY: AUTHORIZED BY : SHIP MASTER :
OWNER'S REPRESENTATIVE:	

C DATA:

SHIP'S OPERATING CONDITION: ______________________________

PORT				STARBOARD			
TIME (sec.)	POSITION (deg.)	TIME (sec.)	POSITION (deg.)	TIME (sec.)	POSITION (deg.)	TIME (sec.)	POSITION (deg.)

TRIAL CATEGORY: OPEN WATER PERFORMANCE

SHEET #9

TRIAL NAME: TURNING CIRCLE MANOEUVRE

DRIFT CORRECTION:

ENGINE SETTING: ____________________

SHIP'S OPERATING CONDITION: ____________________

PORT OR STARBOARD: ____________________

INITIAL HEADING: ____________________

TIME (sec.)	HEADING FROM BASE COURSE (deg.)	CHANGE IN HEADING (deg.)	POSITION (deg.)

TRIAL CATEGORY: OPEN WATER PERFORMANCE

SHEET #1

TRIAL NAME: ZIG ZAG MANOEUVRE

TRIAL OBJECTIVE:

To provide a qualitiative measure of the rudder's ability to initiate and check changes of heading.

EQUIPMENT REQUIRED/PREPARATIONS FOR RECORDING DATA:

Microwave positioning system
Yaw Gyro

Three remote stations, consisting of microwave transponders shall be installed ashore and the distances between them measured. The master station shall be installed on the highest possible spot of the ship.

The ship's doppler speed log may be used to determine the ship's track, providing sea conditions are good, a "bottom lock" is achieved and the accuracy requirements of ≤ 10m or one ship breadth are met. However, the ship's doppler speed log should only be used to support the microwave position system readings.

ENVIRONMENTAL CONDITIONS REQUIRED:

SEA: ≤ Sea State 3
CURRENT: Constant, ∠ 1 m/s
WIND SPEED: ≤ Beaufort 4
VESSEL APPROACH SPEED: ______
WATER DEPTH REQ'D >: ______

WATER DEPTH REQ'D, $D = \frac{5.522HV}{\sqrt{L_{PP}}}$

WHERE D=Minimum depth (m)
H=Trial draft (m)
V=Approach speed (knots)
Lpp=Length between perpendiculars (m)

TRIAL CATEGORY : OPEN WATER PERFORMANCE

SHEET #2

TRIAL NAME : ZIG ZAG MANOEUVRE

PROCEDURE :

To be performed for both the loaded and ballast operating conditions.

1. Hold ship steady on a constant heading at maximum predetermined approach speed for approximately one (1) minute. Once approach speed is "steadied", propulsion controls are not to be manipulated for duration of manoeuvre.
2. Record relevant data in section A of datasheet. The ship's heading is to be recorded in section B every 10 seconds for the duration of the manoeuvre, as well as the ship's position in section C.
3. More rudder smoothly, at maximum rate from center to 20° starboard. The rudder is held in this position until change of heading of 20° is reached. Record specific elapsed times in section C of datasheet.
4. More rudder from 20° starboard (R) to 20° port (L), hold until ship's heading is 20° port of original course. Record data.
5. Repeat step 4, moving rudder 20° Port to 20° starboard.
6. Move rudder 20° starboard to 20° port and hold until original course is restored.

NOTES :

TRIAL CATEGORY: OPEN WATER PERFORMANCE

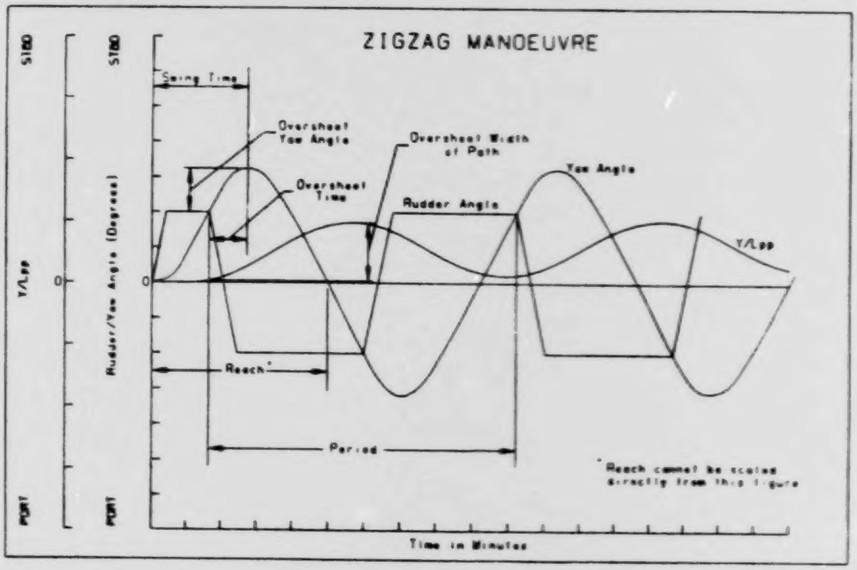
SHEET #3

TRIAL NAME: ZIG ZAG MANOEUVRE

RESULTS:

Graphical presentation, as shown below, of the ship's heading and rudder angle plotted as a function of time, is recommended.

PRESENTATION OF RESULTS:



*Reach cannot be scaled directly from this figure

FROM THE GRAPH THE FOLLOWING VALUES ARE TO TABULATED:

RUDDER ANGLE/CHECK ANGLE: ____°/____° ie.20°/20°

FIRST OVERSHOOT ANGLE		OVERSHOOT TIME	
FINAL OVERSHOOT ANGLE		OVERSHOOT PERIOD	
OVERSHOOT WIDTH		SWING TIME	
		REACH	

OVERSHOOT WIDTH: THE DISTANCE CORRESPONDING TO THE MAXIMUM DISTANCE NORMAL TO THE SHIP'S ORIGNAL PATH MINUS THE DISTANCE NORMAL TO THE SHIP'S ORIGNAL PATH AT THE SECOND EXECUTE.

MANOEUVRE : ______________________

SHIP'S OPERATING CONDITION : ______________

IT SHOULD BE NOTED THAT THE RESPONSE OF THE VESSEL MAY BE DIFFRENT FROM THAT SHOWN IF ANY OF THE FOLLOWING CONDITIONS UPON WHICH THE MANOEUVRING DATA IS BASED, ARE ALTERED:

1. CALM WEATHER ≤ SEA STATE 3
2. WIND ≤ BEAUFORT 4
3. DRAFTS AS SHOWN
4. DEEP WATER CONDITION
5. CONSTANT CURRENT <1 M/S
6. CLEAN HULL

TRIAL CATEGORY : OPEN WATER PERFORMANCE

SHEET #5

TRIAL NAME : ZIG ZAG MANOEUVRE

CONDUCTING AUTHORITY :

OWNER'S REPRESENTATIVE :

PERFORMED BY :
AUTHORIZED BY:
SHIP MASTER :

A DATA:

SHIP NAME : ____________ TEST DATE : ____________
TIME TEST BEGAN : ____________ TIME TEST ENDED : ____________

SHIP'S OPERATING CONDITION: ____________
SHIP HEADING :____________ INITIAL RUDDER ANGLE :____________
INITIAL SHAFT RPM. :____________ APPROACH SPEED : ____________
DEPTH OF WATER : ____________ SEA CONDITION : ____________
WIND VELOCITY : ____________ WIND DIRECTION : ____________
DRAFT AFT. : ____________ DRAFT FWD. : ____________
TRIM : ____________
CONTROLLABLE PITCH SETTING (IF APPL.) : ____________
TRIAL LOCATION : ____________

EQUIPMENT USED: (Ie Manufacturer, Model no., Serial no.)

TRIAL CATEGORY: OPEN WATER PERFORMANCE

SHEET #6

TRIAL NAME: ZIG ZAG MANOEUVRE

CONDUCTING AUTHORITY:

OWNER'S REPRESENTATIVE:

PERFORMED BY:

AUTHORIZED BY:

SHIP MASTER:

B DATA:

RUDDER ANGLE /CHECK ANGLE: 9 ° ie.20°/20°

SHIP'S OPERATING CONDITION:

ELAPSED TIME (sec.)	HEADING (deg.)	DEPARTURE FROM COURSE (deg.)	ELAPSED TIME (sec.)	HEADING (deg.)	DEPARTURE FROM COURSE (deg.)

RUDDER MOVEMENT		ELAPSED TIME	RUDDER MOVEMENT		ELAPSED TIME
1	START 20°R		3	START 20°R	
	ATTAIN 20°R			ATTAIN 20°R	
2	START 20°L		4	START 20°L	
	ATTAIN 20°L			ATTAIN 0°	

TRIAL CATEGORY : OPEN WATER PERFORMANCE

SHEET #7

TRIAL NAME : ZIG ZAG MANOEUVRE

CONDUCTING AUTHORITY :

OWNER'S REPRESENTATIVE :

PERFORMED BY :

AUTHORIZED BY :

SHIP MASTER :

C DATA:

RUDDER ANGLE /CHECK ANGLE: —— —— Ie.20°/20°

SHIP'S OPERATING CONDITION :

TIME (sec.)	POSITION (deg.)	TIME (sec.)	POSITION (deg.)	TIME (sec.)	POSITION (deg.)

TRIAL CATEGORY: OPEN WATER PERFORMANCE

SHEET #1

TRIAL NAME: CRASH-STOP MANOEUVRE

TRIAL OBJECTIVE:

To assess the vessel's stopping ability from the point of view of avoiding collision.

EQUIPMENT REQUIRED/PREPARATIONS FOR RECORDING DATA:

Microwave positioning system/doppler speed log.
Yaw Gyro.

Three remote stations, consisting of microwave transponders, shall be installed ashore and the distances between them measured. The master station shall be installed on the highest possible spot of the ship.

The ship's doppler speed log may be used to determine the ship's track providing sea conditions are good, a "bottom lock" is achieved and the accuracy requirements of $\leq$ 10m or one ship breadth are met. However, the ship's doppler speed log should only be used to support the microwave position system readings.

ENVIRONMENTAL CONDITIONS REQUIRED:

SEA: $\leq$ Sea State 3

CURRENT: Constant, $<$ 1 m/s

WIND SPEED: $\leq$ Beaufort 4

VESSEL APPROACH SPEED: As per datasheets

WATER DEPTH REQ'D >:

WATER DEPTH REQ'D, $D = \frac{5.522HV}{\sqrt{L_{PP}}}$

WHERE D=Minimum depth (m)
H=Trial draft (m)
V=Approach speed (knots)
L_{PP}=Length between perpendiculars (m)

TRIAL CATEGORY : OPEN WATER PERFORMANCE

SHEET #2

TRIAL NAME : CRASH-STOP MANOEUVRE

PROCEDURE :

To be performed for both the loaded and ballast operating conditions.

1. Hold ship steady on a constant heading at a pre-determined approach speed for approximately one (1) minute. Once approach speed is "steadied", propulsion controls are not to be manipulated for duration of manoeuvre.

2. Record relevant data in section A of datasheet.

3. Bridge command is issued with the rudder remaining at midships. Reverse throttles are at a maximum allowable rate. Record data in section B of datasheet. Constant engine setting is to be maintained until ship comes to rest.

4. Repeat manoeuvre for the engine settings listed on the datasheet.

NOTES :

TRIAL CATEGORY: OPEN WATER PERFORMANCE

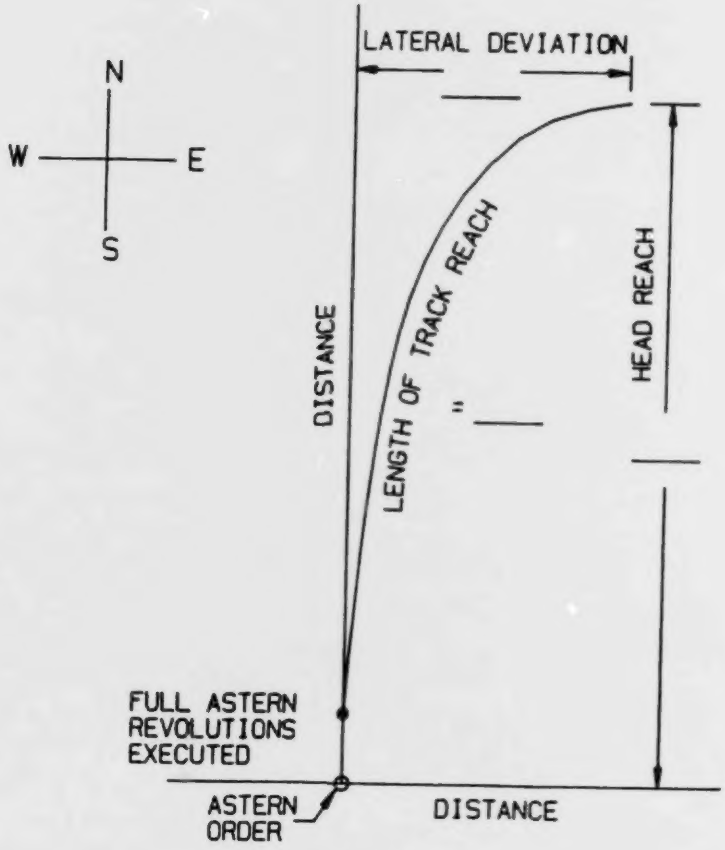
SHEET #3

TRIAL NAME: CRASH-STOP MANOEUVRE

RESULTS:

Graphical presentation, as shown below, of the ship's track, head reach and lateral deviation, is recommended.

PRESENTATION OF RESULTS:



CRASH -STOP MANOEUVRE

TRIAL CATEGORY: OPEN WATER PERFORMANCE

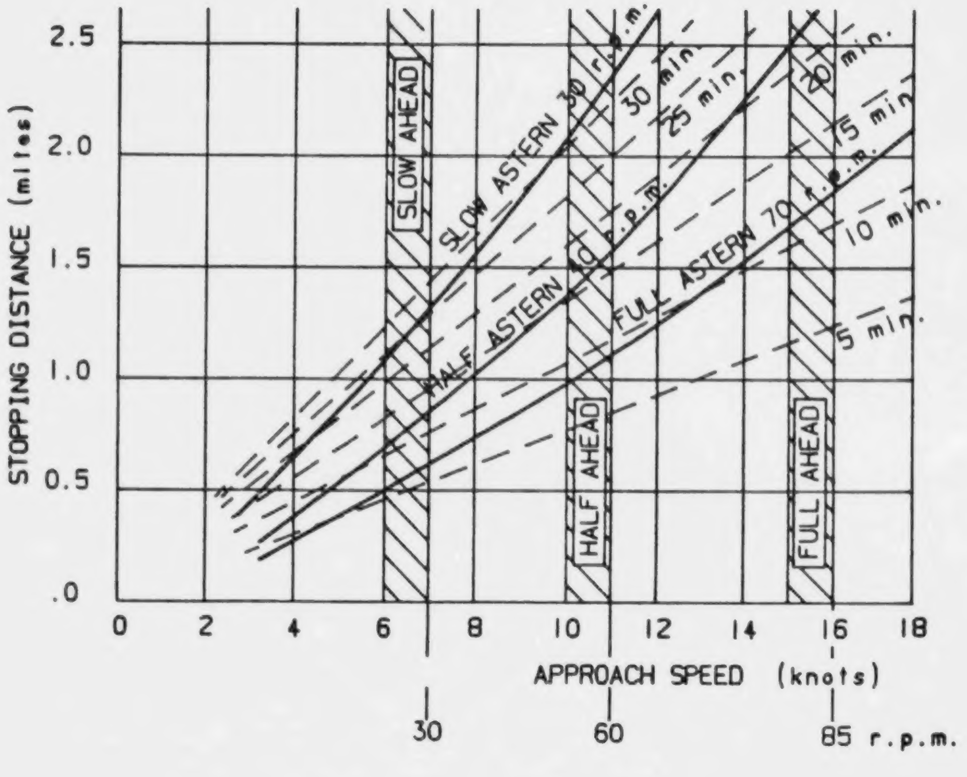
SHEET #4

TRIAL NAME: CRASH-STOP-MANOEUVRE

RESULTS:

Graphical presentation, as shown below, of the ship's stopping distance plotted as a function of approach speed, is recommended.

PRESENTATION OF RESULTS:



STOPPING CURVES DIAGRAM
CRASH-STOP MANOEUVRE

TRIAL CATEGORY : OPEN WATER PERFORMANCE

SHEET #5

TRIAL NAME : CRASH-STOP MANOEUVRE

RESULTS:

SHIP'S NAME :

SHIP'S OPERATING CONDITION :

TRIAL LOCATION:

	A	B	C	D
ITEM	FULL AHEAD TO FULL ASTERN	FULL AHEAD TO ENGINES STOPPED	FULL ASTERN FULL AHEAD	
TEST DATE				
TIME TEST BEGIN				
DRAFT AFT.				
DRAFT FWD.				
TRIM				
APPROACH SPEED				
INITIAL SHAFT RPM				
AHEAD POWER, KW				
CONTROLLABLE PITCH SETTING (IF APPL.)				
TIME TO RECH ZERO PITCH RATIO				
TIME TO REACH FULL PITCH ASTERN				
STEADY ASTERN TORQUE, NM				
STEADY ASTERN SHAFT RPM				
ASTERN POWER, KW				
ASTERN POWER/AHEAD PWR%				
HEAD REACH				
TRACK REACH				
LATERAL DEVIATION				
TIME TO STOP SHIP				

MANOEUVRE : ______________________

SHIP'S OPERATING CONDITION : ______________

IT SHOULD BE NOTED THAT THE RESPONSE OF THE VESSEL MAY BE DIFFRENT FROM THAT SHOWN IF ANY OF THE FOLLOWING CONDITIONS UPON WHICH THE MANOEUVRING DATA IS BASED, ARE ALTERED:

1. CALM WEATHER ≤ SEA STATE 3
2. WIND ≤ BEAUFORT 4
3. DRAFTS AS SHOWN
4. DEEP WATER CONDITION
5. CONSTANT CURRENT <1 M/S
6. CLEAN HULL

TRIAL CATEGORY: OPEN WATER PERFORMANCE

SHEET #7

TRIAL NAME: CRASH-STOP MANOEUVRE

CONDUCTING AUTHORITY:

OWNER'S REPRESENTATIVE:

PERFORMED BY:

AUTHORIZED BY:

SHIP MASTER:

A DATA:

SHIP'S NAME : ______

SHIP'S OPERATING CONDITION: ______

TRIAL LOCATION : ______

ITEM	A FULL AHEAD TO FULL ASTERN	B FULL AHEAD TO ENGINES STOPPED	C FULL ASTERN TO FULL AHEAD	D
TEST DATE				
TIME TEST BEGAN				
SHIP'S HEADING				
INITIAL RUDDER ANGLE				
INITIAL SHAFT RPM				
APPROACH SPEED				
DEPTH OF WATER				
SEA CONDITION				
WIND VELOCITY				
WIND DIRECTION				
DRAFT AFT.				
DRAFT FWD.				
TRIM				
CONTROLLABLE PITCH SETTING (IF APPL.)				
TIME TO REACH ZERO PITCH RATIO				
TIME TO REACH FULL PITCH ASTERN				
STEADY ASTERN TORQUE, NM				
STEADY ASTERN SHAFT RPM				
ASTERN POWER, KW				
TIME TO STOP SHIP				
FINAL HEADING				

TRIAL CATEGORY : OPEN WATER PERFORMANCE	SHEET #8
TRIAL NAME : CRASH-STOP MANOEUVRE	

CONDUCTING AUTHORITY :	PERFORMED BY : AUTHORIZED BY : SHIP MASTER :
OWNER'S REPRESENTATIVE :	

B DATA:

SHIP'S OPERATING CONDITION : ____________________

TIME (sec.)	POSITION (deg.)	TIME (sec.)	POSITION (deg.)	TIME (sec.)	POSITION (deg.)

EQUIPMENT USED: (Manufacturer, Model no., Serial no.)

TRIAL CATEGORY: OPEN WATER PERFORMANCE

SHEET #1

TRIAL NAME: THE DIEUDONNÉ SPIRAL MANOEUVRE

TRIAL OBJECTIVE:

To determine the directional stability characteristics of a ship.

EQUIPMENT REQUIRED/PREPARATIONS FOR RECORDING DATA:

Yaw Gyro.

ENVIRONMENTAL CONDITIONS REQUIRED:

SEA: Calm

CURRENT: Constant, ≤ 1 m/s

WIND SPEED: ≤ 5 Knots

VESSEL APPROACH SPEED: ________

WATER DEPTH REQ'D >: ________

WATER DEPTH REQ'D, $D = \frac{5.522HV}{\sqrt{L_{PP}}}$

WHERE D=Minimum depth (m)

H=Trial draft (m)

V=Approach speed (knots)

Lpp=Length between perpendiculars (m)

TRIAL CATEGORY : OPEN WATER PERFORMANCE

SHEET #2

TRIAL NAME : THE DIEUDONNÉ SPIRAL MANOEUVRE

PROCEDURE :

To be performed for both the loaded and ballast operating conditions.

1. Hold ship steady on a constant heading at maximum pre-determined approach speed for approximately one (1) minute. Once approach speed is "steadied", propulsion controls are not to be manipulated for duration of manoeuvre.
2. Record relevant data in section A of datasheet.
3. After approximately one (1) minute, lay rudder starboard to an angle, δ of 15°R and hold until the rate of change in ship heading, ψ, becomes constant.*
4. Repeat step 3 for all rudder settings listed on datasheet.

*Only when the rates of change of heading are found to be constant for at least six (6) consecutive readings is the rudder ordered to the next position.

NOTES :

It is essential that the manoeuvre be executed in a continuous process. If an interruption occurs during the manoeuvre, the trial must be repeated, as the change in heading may no longer be in the required direction. Furthermore, it is imperative that sufficient time is taken to "steady" the rate of change in ship heading at each rudder angle, otherwise spurious results are obtained.

TRIAL CATEGORY: OPEN WATER PERFORMANCE

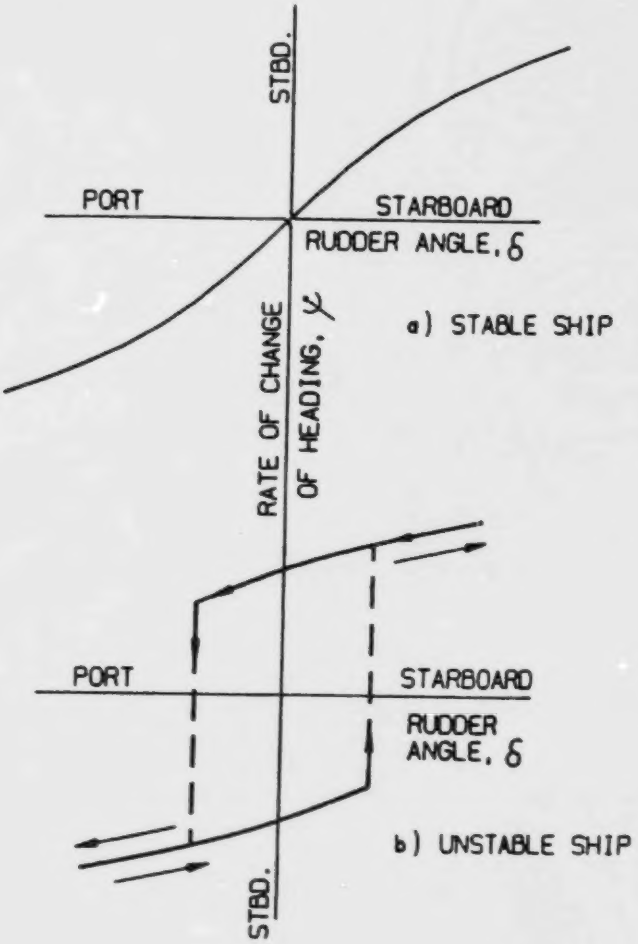
SHEET #3

TRIAL NAME: THE DIEUDONNÉ SPIRAL MANOEUVRE

RESULTS:

Graphical presentation, as shown below, of the rate of change of ship heading, $\dot{\psi}$, as a function of rudder angle, δ, is recommended.

PRESENTATION OF RESULTS:



THE DIEUDONNÉ SPIRAL MANOEUVRE

SHIP'S OPERATING CONDITION: ________

TRIAL CATEGORY : OPEN WATER PERFORMANCE

SHEET #4

TRIAL NAME : THE DIEUDONNÉ SPIRAL MANOEUVRE

RESULTS:

SHIP NAME :
TEST DATE:
TIME TEST BEGIN:
TIME TEST ENDED:
SHIP'S OPERATING CONDITION:
SHIP HEADING :
INITIAL RUDDER ANGLE :
INITIAL SHAFT RPM. :
APPROACH SPEED :
DEPTH OF WATER :
SEA CONDITION :
WIND VELOCITY :
WIND DIRECTION :
DRAFT AFT. :
DRAFT FWD. :
TRIM :
TRIAL LOCATION:

STEP	RUDDER ANGLE δ (deg.)	CONSTANT RATE OF CHANGE IN SHIP HEADING, $\dot{\psi}$, (deg./sec.)
1	15R	
2	10R	
3	5R	
4	3R	
5	1R	
6	0	
7	1L	
8	3L	
9	5L	
10	10L	
11	15L	
12	10L	
13	5L	
14	3L	
15	1L	
16	0	
17	1R	
18	3R	
19	5R	
20	10R	
21	15R	

MANOEUVRE : ______________________

SHIP'S OPERATING CONDITION : ______________

IT SHOULD BE NOTED THAT THE RESPONSE OF THE VESSEL MAY BE DIFFRENT FROM THAT SHOWN IF ANY OF THE FOLLOWING CONDITIONS UPON WHICH THE MANOEUVRING DATA IS BASED, ARE ALTERED:

1. CALM WEATHER ≤ SEA STATE 3
2. WIND ≤ BEAUFORT 4
3. DRAFTS AS SHOWN
4. DEEP WATER CONDITION
5. CONSTANT CURRENT <1 M/S
6. CLEAN HULL

TRIAL CATEGORY : OPEN WATER PERFORMANCE

SHEET #6

TRIAL NAME : THE DIEUDONNÉ SPIRAL MANOEUVRE

CONDUCTING AUTHORITY :	PERFORMED BY : AUTHORIZED BY: SHIP MASTER :
OWNER'S REPRESENTATIVE :	

A DATA:

SHIP NAME : ______________ TEST DATE : ______________

TIME TEST BEGAN : ______________ TIME TEST ENDED : ______________

SHIP'S OPERATING CONDITION: ______________

SHIP HEADING : ______________ INITIAL RUDDER ANGLE : ______________

INITIAL SHAFT RPM. : ______________ APPROACH SPEED : ______________

DEPTH OF WATER : ______________ SEA CONDITION : ______________

WIND VELOCITY : ______________ WIND DIRECTION : ______________

DRAFT AFT. : ______________ DRAFT FWD. : ______________

TRIM : ______________

CONTROLLABLE PITCH SETTING (IF APPL.) : ______________

TRIAL LOCATION : ______________

EQUIPMENT USED: (ie Manufacturer, Model no., Serial no.)

TRIAL CATEGORY : OPEN WATER PERFORMANCE

SHEET #7

TRIAL NAME : THE DIEUDONNÉ SPIRAL MANOEUVRE

B DATA:

SHIP'S OPERATING CONDITION : ______________________

TIME (sec.)	STEP No. : 1 RUDDER ANGLE : 15R		STEP No. : 2 RUDDER ANGLE : 10R	
	SHIP HEADING (deg.)	Δ SHIP HEADING (deg./sec.)	SHIP HEADING (deg.)	△ SHIP HEADING (deg./sec.)
10				
20				
30				
40				
50				
60				
70				
80				
90				
100				
110				
120				

TIME (sec.)	STEP No. 3 RUDDER ANGLE 5R		STEP No. 4 RUDDER ANGLE 3R	
	SHIP HEADING (deg.)	Δ SHIP HEADING (deg./sec.)	SHIP HEADING (deg.)	△ SHIP HEADING (deg./sec.)
10				
20				
30				
40				
50				
60				
70				
80				
90				
100				
110				
120				

TRIAL CATEGORY : OPEN WATER PERFORMANCE

SHEET #8

TRIAL NAME : THE DIEUDONNÉ SPIRAL MANOEUVRE

B DATA:

SHIP'S OPERATING CONDITION : ______________________________

TIME (sec.)	STEP No.: 5 RUDDER ANGLE : 1R		STEP No. : 6 RUDDER ANGLE : 0	
	SHIP HEADING (deg.)	△ SHIP HEADING (deg./sec.)	SHIP HEADING (deg.)	△ SHIP HEADIN (deg./sec.
10				
20				
30				
40				
50				
60				
70				
80				
90				
100				
110				
120				

TIME (sec.)	STEP No. 7 RUDDER ANGLE 1L		STEP No. 8 RUDDER ANGLE 3L	
	SHIP HEADING (deg.)	△ SHIP HEADING (deg./sec.)	SHIP HEADING (deg.)	△ SHIP HEADIN (deg./sec.)
10				
20				
30				
40				
50				
60				
70				
80				
90				
100				
110				
120				

TRIAL CATEGORY : OPEN WATER PERFORMANCE

SHEET #9

TRIAL NAME : THE DIEUDONNÉ SPIRAL MANOEUVRE

B DATA:

SHIP'S OPERATING CONDITION : ______________________

TIME (sec.)	STEP No.: 9 RUDDER ANGLE : 5L		STEP No. : 10 RUDDER ANGLE : 10L	
	SHIP HEADING (deg.)	Δ SHIP HEADING (deg./sec.)	SHIP HEADING (deg.)	Δ SHIP HEADING (deg./sec.)
10				
20				
30				
40				
50				
60				
70				
80				
90				
100				
110				
120				

TIME (sec.)	STEP No. 11 RUDDER ANGLE 15L		STEP No. 12 RUDDER ANGLE 10L	
	SHIP HEADING (deg.)	Δ SHIP HEADING (deg./sec.)	SHIP HEADING (deg.)	Δ SHIP HEADING (deg./sec.)
10				
20				
30				
40				
50				
60				
70				
80				
90				
100				
110				
120				

TRIAL CATEGORY : OPEN WATER PERFORMANCE

SHEET #10

TRIAL NAME : THE DIEUDONNÉ SPIRAL MANOEUVRE

B DATA:

SHIP'S OPERATING CONDITION : ______________________

TIME (sec.)	STEP No. : 13 RUDDER ANGLE : 5L		STEP No. : 14 RUDDER ANGLE : 3L	
	SHIP HEADING (deg.)	Δ SHIP HEADING (deg./sec.)	SHIP HEADING (deg.)	Δ SHIP HEADING (deg./sec.)
10				
20				
30				
40				
50				
60				
70				
80				
90				
100				
110				
120				

TIME (sec.)	STEP No. 15 RUDDER ANGLE 1L		STEP No. 16 RUDDER ANGLE 0	
	SHIP HEADING (deg.)	Δ SHIP HEADING (deg./sec.)	SHIP HEADING (deg.)	Δ SHIP HEADING (deg./sec.)
10				
20				
30				
40				
50				
60				
70				
80				
90				
100				
110				
120				

TRIAL CATEGORY :

OPEN WATER PERFORMANCE

SHEET #11

TRIAL NAME :

THE DIEUDONNÉ SPIRAL MANOEUVRE

B DATA:

SHIP'S OPERATING CONDITION : ____________________

TIME (sec.)	STEP No. : 17 RUDDER ANGLE : 1R		STEP No. : 18 RUDDER ANGLE : 3R	
	SHIP HEADING (deg.)	Δ SHIP HEADING (deg./sec.)	SHIP HEADING (deg.)	△ SHIP HEADING (deg./sec.)
10				
20				
30				
40				
50				
60				
70				
80				
90				
100				
110				
120				

TIME (sec.)	STEP No. 19 RUDDER ANGLE 5R		STEP No. 20 RUDDER ANGLE 10R	
	SHIP HEADING (deg.)	Δ SHIP HEADING (deg./sec.)	SHIP HEADING (deg.)	△ SHIP HEADING (deg./sec.)
10				
20				
30				
40				
50				
60				
70				
80				
90				
100				
110				
120				

TRIAL CATEGORY : OPEN WATER PERFORMANCE

SHEET #12

TRIAL NAME : THE DIEUDONNÉ SPIRAL MANOEUVRE

B DATA:

SHIP'S OPERATING CONDITION : ____________________

TIME (sec.)	STEP No. : 21 RUDDER ANGLE : 15R		STEP No. : RUDDER ANGLE :	
	SHIP HEADING (deg.)	Δ SHIP HEADING (deg./sec.)	SHIP HEADING (deg.)	△ SHIP HEADING (deg./sec.)
10				
20				
30				
40				
50				
60				
70				
80				
90				
100				
110				
120				

TIME (sec.)	STEP No. RUDDER ANGLE		STEP No. RUDDER ANGLE	
	SHIP HEADING (deg.)	Δ SHIP HEADING (deg./sec.)	SHIP HEADING (deg.)	△ SHIP HEADING (deg./sec.)
10				
20				
30				
40				
50				
60				
70				
80				
90				
100				
110				
120				

TRIAL CATEGORY: OPEN WATER PERFORMANCE

SHEET #1

TRIAL NAME: MAN-OVERBROAD - WILLIAMSON TURN

TRIAL OBJECTIVE:

To evaluate the ship's ability to perform the Williamson Turn Manoeuvre effectively.

EQUIPMENT REQUIRED/PREPARATIONS FOR RECORDING DATA:

Microwave positioning system.
Yaw Gyro.

Three remote stations, consisting of microwave transponders shall be installed ashore and the distances between them measured. The master station shall be installed on the highest possible spot of the ship.

The ship's doppler speed log may be used to determine the ship's track providing sea conditions are good, a "bottom lock" is achieved and the accuracy requirements of less than or equal to 10m or one ship breadth are met.

However the ship's doppler speed log should only be used to support the microwave position system readings.

ENVIRONMENTAL CONDITIONS REQUIRED:

SEA: ≤ Sea State 3
CURRENT: Constant, < 1 m/s
WIND SPEED: ≤ Beaufort 4
VESSEL APPROACH SPEED: Full Speed Ahead
WATER DEPTH REQ'D >: ____

WATER DEPTH REQ'D, $D = \frac{5.522HV}{\sqrt{L_{pp}}}$

WHERE D=Minimum depth (m)
H=Trial draft (m)
V=Approach speed (knots)
Lpp=Length between perpendiculars (m)

TRIAL CATEGORY OPEN WATER PERFORMANCE

SHEET #2

TRIAL NAME : MAN-OVERBOARD - WILLIAMSON TURN

PROCEDURE :

To be performed for both the loaded and ballast operating conditions, port and starboard turns.

1. Hold ship steady on a constant heading, full ahead, for approximately one (1) minute.
2. Record relevant data in section A of datasheet. Record ship's position in section B every 10 seconds for the duration of the manoeuvre.
3. Man-overboard signal is given.
4. More rudder hardover in direction corresponding to side over which man (2) fell. Stop inboard engine.
5. When clear of man, order full ahead on all engines, continue to use full rudder.
6. When ship's heading has changed 60° from original course, move rudder in opposite direcion by 60°. Hold this rudder angle until ready to steady on reciprocal of original course.
7. Use engines and rudder to position ship upwind of man until ship dead in dead-in-water, and man well forward of propellers.

NOTES :

1. It is recommended that this trial be executed during the acceptance trials of the vessel's lifesaving equipment.
2. For the purpose of simulation, a suitable marker is to be used to represent the man overboard.

TRIAL CATEGORY: OPEN WATER PERFORMANCE

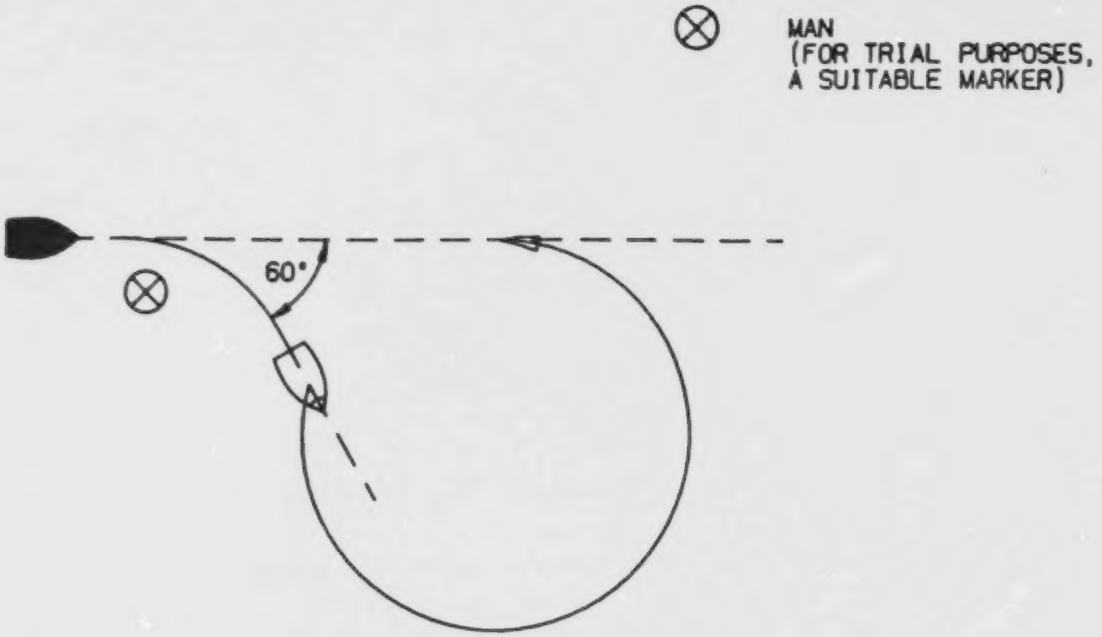
SHEET #3

TRIAL NAME: MAN-OVERBOARD - WILLIAMSON TURN

RESULTS:

A diagram of the ship's track, as shown below, is recommended.

PRESENTATION OF RESULTS:



ELAPSED TIME: ______________

WILLIAMSON TURN MANOEUVRE

SHEET #4

MANOEUVRE : ______________________________

SHIP'S OPERATING CONDITION : ____________________

IT SHOULD BE NOTED THAT THE RESPONSE OF THE VESSEL MAY BE DIFFRENT FROM THAT SHOWN IF ANY OF THE FOLLOWING CONDITIONS UPON WHICH THE MANOEUVRING DATA IS BASED, ARE ALTERED:

1. CALM WEATHER ≤ SEA STATE 3
2. WIND ≤ BEAUFORT 4
3. DRAFTS AS SHOWN
4. DEEP WATER CONDITION
5. CONSTANT CURRENT <1 M/S
6. CLEAN HULL

TRIAL CATEGORY: OPEN WATER PERFORMANCE

SHEET #5

TRIAL NAME: MAN-OVERBOARD - WILLIAMSON TURN

CONDUCTING AUTHORITY:

OWNER'S REPRESENTATIVE:

PERFORMED BY:

AUTHORIZED BY:

SHIP MASTER:

A DATA:

SHIP NAME: ______ TEST DATE: ______

SHIP'S OPERATING CONDITION: ______

DEPTH OF WATER: ______ SEA CONDITION: ______

WIND VELOCITY: ______ WIND DIRECTION: ______

DRAFT AFT.: ______ DRAFT FWD.: ______

TRIM: ______

TRIAL LOCATION: ______

ITEM	PORT	STARBOARD
TIME TEST BEGAN		
TIME TEST ENDED		
SHIP'S HEADING		
INITIAL RUDDER ANGLE		
INITIAL SHAFT RPM.		
APPROACH SPEED		
CONTROLLABLE PITCH SETTING (IF APPL.)		

EQUIPMENT USED: (ie.Manufacturer,Model no.,Serial no.)

TRIAL CATEGORY:	OPEN WATER PERFORMANCE	SHEET #6
TRIAL NAME:	MAN-OVERBOARD - WILLIAMSON TURN	

CONDUCTING AUTHORITY:	PERFORMED BY: AUTHORIZED BY:
OWNER'S REPRESENTATIVE:	SHIP MASTER:

B DATA:

SHIP'S OPERATING CONDITION:

PORT			STARBOARD		
TIME (sec.)	HEADING (deg.)	RATE OF TURN (deg./sec.)	TIME (sec.)	HEADING (deg.)	RATE OF TURN (deg./sec.)

TRIAL CATEGORY: OPEN WATER PERFORMANCCE

SHEET #1

TRIAL NAME: THRUSTER TESTS

TRIAL OBJECTIVE:

To determine the effect of forward speed on turning performance.

EQUIPMENT REQUIRED/PREPARATIONS FOR RECORDING DATA:

Yaw Gyro

ENVIRONMENTAL CONDITIONS REQUIRED:

SEA: $\leq$ Sea State 3

CURRENT: Constant, $<$ 1 m/s

WIND SPEED: $\leq$ Beaufort 4

VESSEL APPROACH SPEED: As per datasheets

WATER DEPTH REQ'D >: ____

WATER DEPTH REQ'D, $D = \frac{5.522HV}{\sqrt{L_{PP}}}$

WHERE D=Minimum depth (m)

H=Trial draft (m)

V=Approach speed (knots)

Lpp=Length between perpendiculars (m)

TRIAL CATEGORY : OPEN WATER PERFORMANCE

SHEET #2

TRIAL NAME : THRUSTER TESTS

PROCEDURE :

To be performed for both the loaded and ballast conditions.

1. With ship dead-in-water heading into the wind, operate the bow thruster at full thrust(1) for 10 minutes or until the ship's heading changes 30° to the left of the original heading, whichever occurs first. Reverse the bow thruster and repeat(2) Record data in section A and ship's heading at 10 second intervals for the duration of the manoeuvre.

2. With the ship moving ahead, into the wind, at shaft RPM corresponding to 3.0 knots, execute the following manoeuvre:

   a) Operate bow thruster at full thrust and use full rudder to change ship's heading 30° to left of original heading.

   b) Use bow thruster and full rudder to swing ship 30° to the right of original heading.

   c) Repeat 2(a) and (b) above, using full rudder without bow thruster.

NOTES :

1. Submergence of thruster axis $\geq$ 0.8 thruster diameter.

2. Other thrust devices, such as stern thrusters and active rudders may be tested similarly.

TRIAL CATEGORY: OPEN WATER PERFORMANCE

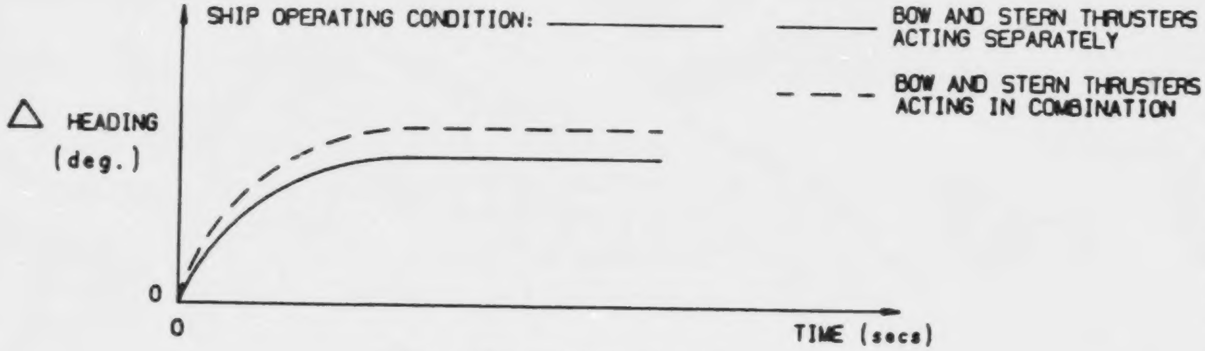
SHEET #3

TRIAL NAME: THRUSTER TESTS

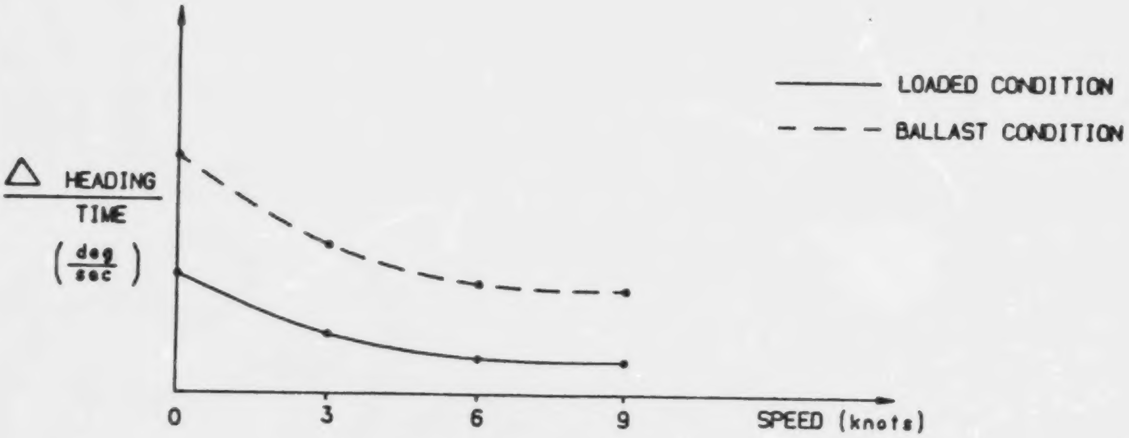
RESULTS:

Diagrams of turning performance at zero forward speed in the full load or ballast condition should be shown, for bow and stern thrusters acting separately and in combination. Diagrams showing the effect of forward speed on turning performance should also be included.

PRESENTATION OF RESULTS:



TURNING PERFORMANCE AT ZERO FORWARD SPEED



THE EFFECT OF FORWARD SPEED ON TURNING PERFORMANCE

MANOEUVRE : ____________________

SHIP'S OPERATING CONDITION : ____________________

IT SHOULD BE NOTED THAT THE RESPONSE OF THE VESSEL MAY BE DIFFRENT FROM THAT SHOWN IF ANY OF THE FOLLOWING CONDITIONS UPON WHICH THE MANOEUVRING DATA IS BASED, ARE ALTERED:

1. CALM WEATHER ≤ SEA STATE 3
2. WIND ≤ BEAUFORT 4
3. DRAFTS AS SHOWN
4. DEEP WATER CONDITION
5. CONSTANT CURRENT <1 M/S
6. CLEAN HULL

TRIAL CATEGORY : OPEN WATER PERFORMANCE	SHEET #5
TRIAL NAME : THRUSTER TESTS	
CONDUCTING AUTHORITY :	PERFORMED BY : AUTHORIZED BY: SHIP MASTER :
OWNER'S REPRESENTATIVE :	

A DATA:

SHIP NAME : ____________ TEST DATE : ____________

TIME TEST BEGAN : ____________ TIME TEST ENDED : ____________

SHIP'S OPERATING CONDITION: ____________

SHIP HEADING : ____________ INITIAL RUDDER ANGLE : ____________

INITIAL SHAFT RPM. : ____________ APPROACH SPEED : ____________

DEPTH OF WATER : ____________ SEA CONDITION : ____________

WIND VELOCITY : ____________ WIND DIRECTION : ____________

DRAFT AFT. : ____________ DRAFT FWD. : ____________

TRIM : ____________

CONTROLLABLE PITCH SETTING (IF APPL.) : ____________

TRIAL LOCATION : ____________

EQUIPMENT USED: (ie Manufacturer, Model no., Serial no.)

TRIAL CATEGORY:	OPEN WATER PERFORMANCE
TRIAL NAME:	THRUSTER TESTS

SHEET #6

CONDUCTING AUTHORITY	PERFORMED BY: AUTHORIZED BY: SHIP MASTER:
OWNER'S REPRESENTATIVE:	

B DATA:

SHIP'S OPERATING CONDITION: ______________________

	0 KNOTS		3 KNOTS			
	BOW THRUSTER ONLY		BOW THRUSTER & FULL RUDDER		RUDDER ONLY	
ELAPSED TIME (sec.)	HEADING (deg.)	CHANGE IN HEADING	HEADING (deg.)	CHANGE IN HEADING	HEADING (deg.)	CHANGE IN HEADING

TRIAL CATEGORY: OPEN WATER PERFORMANCE

SHEET #1

TRIAL NAME: THE PULL-OUT MANOEUVRE

TRIAL OBJECTIVE:

To provide a relatively quick and easy indication of a ship's course stability.

EQUIPMENT REQUIRED/PREPARATIONS FOR RECORDING DATA:

Yaw Gyro.

ENVIRONMENTAL CONDITIONS REQUIRED:

SEA: $\leq$ Sea State 2

CURRENT: Constant, $<$ 1 m/s

WIND SPEED: $\leq$ Beaufort 2

VESSEL APPROACH SPEED: Full Ahead

WATER DEPTH REQ'D $>$: ____________

WATER DEPTH REQ'D, $D = \frac{5.522HV}{\sqrt{L_{PP}}}$

WHERE D=Minimum depth (m)

H=Trial draft (m)

V=Approach speed (knots)

L_{PP}=Length between perpendiculars (m)

TRIAL CATEGORY :	OPEN WATER PERFORMANCE	SHEET #2
TRIAL NAME :	THE PULL-OUT MANOEUVRE	

PROCEDURE :

To be performed for both the loaded and ballast operating conditions, as well as to both port and starboard.

1. Hold ship steady on a constant heading, full ahead, for approximately one (1) minute.
2. Record relevant data in section A of data sheet. Record ship's heading in section B every 10 seconds for the duration of the manoeuvre, and if possible, the ship's rate of turn.
3. Apply a rudder angle of 20° port.
4. Once a steady rate of turn is achieved, return the rudder to midships. The rate of turn is now allowed to decay with the rudder held amidships.
5. Repeat steps 3 and 4, applying a rudder angle of 20° starboard.

NOTES :

TRIAL CATEGORY: OPEN WATER PERFORMANCE

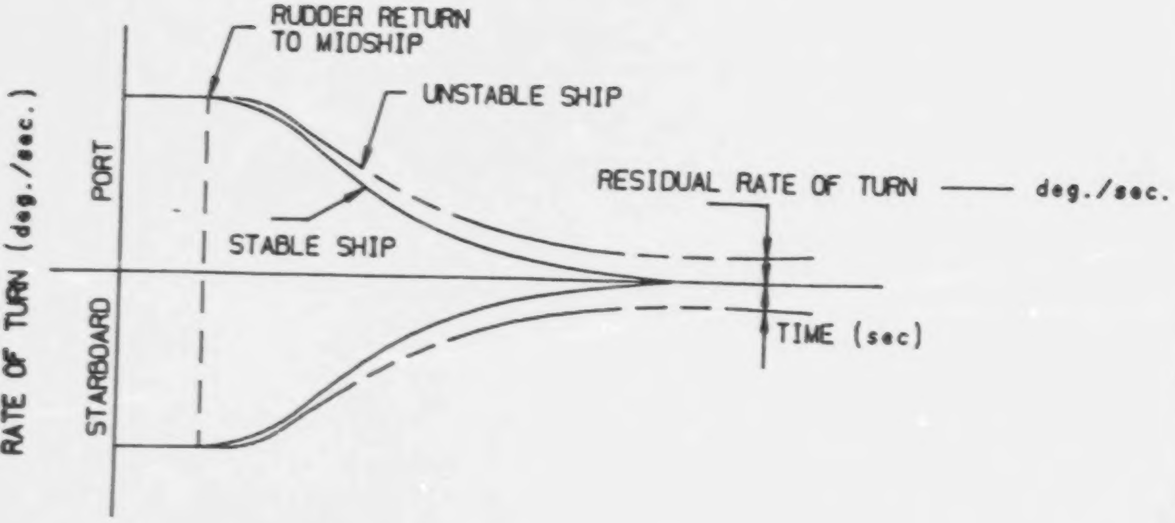
SHEET #3

TRIAL NAME: THE PULL-OUT MANOEUVRE

RESULTS:

The results are to be presented in graphical form as shown below by the diagram.

PRESENTATION OF RESULTS:



THE PULL-OUT MANOEUVRE

SHEET #4

MANOEUVRE : ______________________

SHIP'S OPERATING CONDITION : ______________

IT SHOULD BE NOTED THAT THE RESPONSE OF THE VESSEL MAY BE DIFFRENT FROM THAT SHOWN IF ANY OF THE FOLLOWING CONDITIONS UPON WHICH THE MANOEUVRING DATA IS BASED, ARE ALTERED:

1. CALM WEATHER ≤ SEA STATE 2
2. WIND ≤ BEAUFORT 2
3. DRAFTS AS SHOWN
4. DEEP WATER CONDITION
5. CONSTANT CURRENT <1 M/S
6. CLEAN HULL

TRIAL CATEGORY:
OPEN WATER PERFORMANCE

SHEET #5

TRIAL NAME:
THE PULL-OUT MANOEUVRE

CONDUCTING AUTHORITY:

OWNER'S REPRESENTATIVE:

PERFORMED BY:

AUTHORIZED BY:

SHIP MASTER:

A DATA:

SHIP NAME:——— TEST DATE:———

SHIP'S OPERATING CONDITION:———

DEPTH OF WATER:——— SEA CONDITION:———

WIND VELOCITY:——— WIND DIRECTION:———

DRAFT AFT.:——— DRAFT FWD.:———

TRIM:———

TRIAL LOCATION:———

ITEM	PORT	STARBOARD
TIME TEST BEGAN		
TIME TEST ENDED		
SHIP'S HEADING		
INITIAL RUDDER ANGLE		
INITIAL SHAFT RPM.		
APPROACH SPEED		
CONTROLLABLE PITCH		
SETTING (IF APPL.)		

EQUIPMENT USED: (ie.Manufacturer,Model no.,Serial no.)

TRIAL CATEGORY: OPEN WATER PERFORMACNE

SHEET #6

TRIAL NAME: THE PULL-OUT MANOEUVRE

CONDUCTING AUTHORITY:

OWNER'S REPRESENTATIVE:

PERFORMED BY:

AUTHORIZED BY:

SHIP MASTER:

B DATA:

SHIP'S OPERATING CONDITION: ______________________

PORT			STARBOARD		
TIME (sec.)	HEADING (deg.)	RATE OF TURN (deg./sec.)	TIME (sec.)	HEADING (deg.)	RATE OF TURN (deg./sec.)

APPENDIX F

DRIFT CORRECTION PROCEDURE

1. METHOD OF CORRECTION OF TURNING CIRCLE PLOTS FOR DRIFT

If the ship's track is a perfect circle and repeated turns coincide, there is no drift. However, if the ship's track results in distorted circles, none of which coincide, drift must be considered and the turning circle corrected. The following procedure is recommended by SNAME (Ref. 3) for drift correction:

2. PLOTTING OVERGROUND TRACK

Shore based reference station data results in a plot of the ship's overground track (ie. over the sea floor), thus reflecting the particular conditions present during the trial. Once the degree and location of distortion is determined, the ship's track can be corrected and the true turning characteristics of the vessel measured. The ship's overground track is to be plotted as follows:

1. Plot change of ship's heading as a function of time.

2. Plot ship's position as a function of time.

3. Using the position/time plot, determine the ship's position for each 30 second time interval.

4. Taking the initial ship's heading as the base course for the horizontal axis and orienting the plot to show the ship approaching from top left for a right turn (or a bottom left for a left turn), plot ship's position at 30 second intervals using rectangular coordinates.

5. Fair a dashed line through the plotted points. This represents the overground track of the vessel during the manoeuvre.

3. DETERMINATION OF DRIFT

1. During the manoeuvre the ship will change heading by 540°, therefore the second circle will lap the first by 180°. Somewhere during this lapped sector, the draft displacement will be a maximum and the turning rates of both the first and second circle steady.

2. Determine from the heading change/time plot, the time corresponding to heading changes of 10° intervals for the portion of the lapped sector of the first circle for which the turning rate is steady and the displacement of the second circle a maximum. Similarly determine the time to reach these heading change points plus 360°. Referring to the position/time plot, determine the ship's position at these times. Plot these positions as shown by the Figure CI.

3. Connect the plotted position points at which the ship's heading is 360° apart and which lie within the portion of the lapped sector for which turning rate is steady.

   Referring to the scale of the plot, the mean length of these connections will correspond to the distance drifted by the vessel during a full turn. The mean direction of the connections will be the shift of the second circle relative to the first which is the direction of drift relative to the base course. Drift direction in compass terms can be obtained by adding or subtracting the base course reading.

4. DETERMINATION OF DRIFT RATE

Using the time versus change of heading plot:

1. Determine the time from "execute position" to reach each of the connected points.

2. Subtract the time to reach the heading the first time from the time to reach it the second time.

3. The mean of these values is taken as the mean time to turn 360°.

4. $$\text{Drift rate (inches of plot/sec)} = \frac{\text{mean drift distance (in)}}{\text{mean time to turn } 360^\circ \text{ (sec)}}$$

$$\text{Drift rate (knots)} = \frac{\text{Drift rate (in/sec)} \times \text{scale (ft/in)}}{\text{Dimensional constant (Feet/nautical mile)(hour/sec)}}$$

5. PLOTTING THE DRIFT CORRECTED TURNING CIRCLE

1. Referring to the time plots, determine the time to or from "execute position" for each plotted point of the overground plot.

2. Multiplying each of these times by the drift rate results in the drift distance in inches of plot.

3. Assume the execution position as the origin representing zero time and zero drift. Extend a line from each plotted point in a direction opposite to the direction of drift after "execute", and in the direction of drift prior to "execute".

4. Multiply the time of each plotted point by the drift rate (in. of plot/sec) and mark the distance on these lines. These points define the drift corrected track.

5. Using the portion of the ship's track in which the turning rate is steady, determine a best fit center.

6. Draw a best-fit circle around this center.

7. Fair a line through the remaining points and correct the base course.

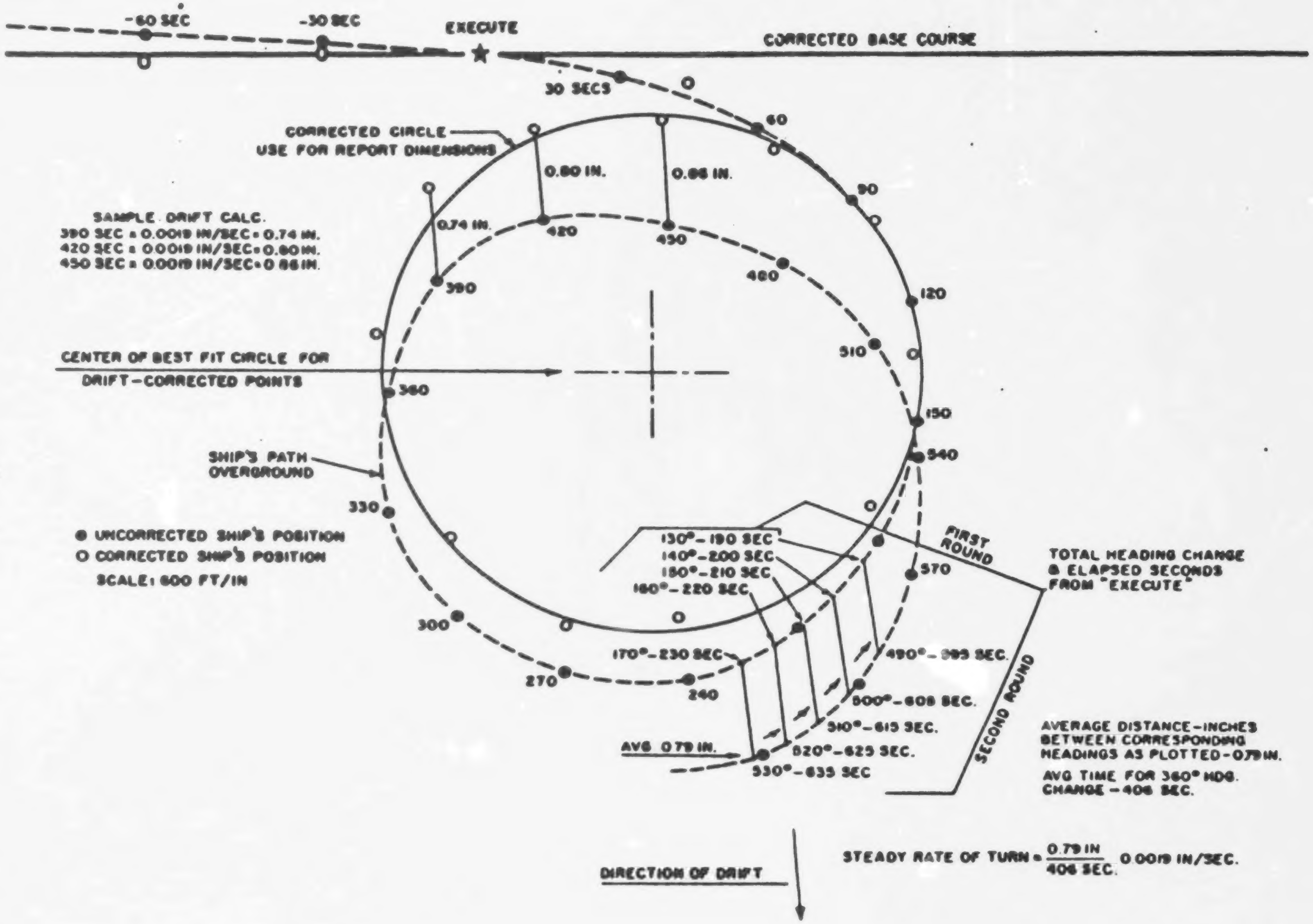

-60 SEC
-30 SEC
EXECUTE
CORRECTED BASE COURSE
30 SECS
60
90
120
150
540
570
CORRECTED CIRCLE
USE FOR REPORT DIMENSIONS
0.80 IN.
0.86 IN.
0.74 IN.
SAMPLE DRIFT CALC.
390 SEC × 0.0019 IN/SEC = 0.74 IN.
420 SEC × 0.0019 IN/SEC = 0.80 IN.
450 SEC × 0.0019 IN/SEC = 0.86 IN.
420
450
480
390
510
CENTER OF BEST FIT CIRCLE FOR
DRIFT-CORRECTED POINTS
360
SHIP'S PATH
OVERGROUND
330
● UNCORRECTED SHIP'S POSITION
○ CORRECTED SHIP'S POSITION
SCALE: 600 FT/IN
300
270
240
130°-190 SEC
140°-200 SEC
150°-210 SEC
160°-220 SEC
170°-230 SEC
FIRST ROUND
TOTAL HEADING CHANGE & ELAPSED SECONDS FROM "EXECUTE"
490°-595 SEC.
500°-608 SEC.
510°-615 SEC.
520°-625 SEC.
530°-635 SEC
SECOND ROUND
AVG 0.79 IN.
AVERAGE DISTANCE-INCHES BETWEEN CORRESPONDING HEADINGS AS PLOTTED-0.79 IN.
AVG TIME FOR 360° HDG. CHANGE - 406 SEC.
DIRECTION OF DRIFT
STEADY RATE OF TURN = 0.79 IN / 406 SEC. 0.0019 IN/SEC.

Fig C1 Method of Drift Correction for Turning Circle Plots

APPENDIX G

INTERNATIONAL MARITIME ORGANIZATION - INFORMATION PAPER

SUB-COMMITTEE ON SHIP DESIGN
AND EQUIPMENT - 32nd session
Agenda item _________

MANOEUVRABILITY OF SHIPS - MANOEUVRING STANDARDS

Submitted by Canada

1.0 INTRODUCTION

1.1 This paper presents the results and conclusions from a program of work sponsored by the Department of Transport of the Government of Canada. Its objectives were to undertake several of the activities recommended by the Sub-Committee on Ship Design and Equipment, of the International Maritime Organization (IMO) at its meetings DE 29/14, and to provide thereby additional information of the type required to assess how the regulatory framework for ship manoeuvring should best be developed.

1.2 The work included the review of methodologies available for manoeuvring prediction, the development from these of tools available for use by designers and/or regulators, and their testing and validation against accurately controlled full scale trials. Inherent problems with the use of such methods as are currently available were highlighted, and the significance of these for regulators has been assessed. In addition, a standard "Sea Trials Program" was developed which included procedures for conducting manoeuvring trials, recommended equipment and levels of accuracy for recording trials data, the type of data to be recorded, and a standard format for recording the data.

2.0 BACKGROUND

2.1 In recent years, the IMO has directed several initiatives with respect to the manoeuvrability of ships. These initiatives have included the development of a "Manoeuvring Booklet" and "Pilot Card", both of which were designed to standardize the type and format of manoeuvring data available on board a ship.

2.2 The IMO has also been actively working towards the development of manoeuvring standards. Canada, for her part, was involved in a study (ref. 10, Annex A) which supplemented previous work by the United States (ref. 11, Annex A). The project completed by Canada, however, raised several questions as noted by the Sub-Committee during its 31st session (DE 31/3). A new project was initiated by Canada and has now been completed.

3.0 PROJECT OBJECTIVES

3.1 During the last session of the Sub-Committee on Ship Design and Equipment (DE 31/3), Canada's submission outlined the objectives of the recently completed study. There were five (5) primary objectives.

.1 The development of a "Sea Trials Program", consistent with the recommendations made in MSC/Circ. 389, which specified a standardized set of sea trials, procedures for their execution, methods for recording the data, and data to be gathered.

.2 The identification of a method or methods suitable for use by a naval architect, in the preliminary design phase, to estimate the manoeuvring performance of a vessel.

.3 The computer coding and application of the above methods to two ship types of particular interest to Canada.

.4 The execution of accurate full-scale trials for the two types, based on the proposed standardized trials, as specified in the "Sea Trials Program".

.5 The comparison of results between theoretical estimates and full-scale trials.

4.0 SEA TRIALS PROGRAM

4.1 A "Sea Trials Program" was developed, consistent with the information contained in references 1 to 6, (refer to Annex A of this document).

4.2 The sea trials which were included in the program are the:

.1 Turning circle manoeuvre.
.2 Zigzag (or Kempf) manoeuvre.
.3 Dieudonne spiral manoeuvre.
.4 Crash stop manoeuvre.
.5 Pull-out manoeuvre.
.6 Lateral thrusters manoeuvre.
.7 Man-Overboard (Williamson turn) manoeuvre.

4.3 An excerpt from the "Sea Trials Program", describing the turning circle manoeuvre, is included in Annex B. The format for the other trials in the program is similar, and is available for those who are interested.

5.0 MATHEMATICAL MODEL

5.1 An extensive literature survey was conducted during the early stages of the project. The criteria for the selection of a mathematical model were simplicity of use, the degree to which the model used data available at the preliminary design stage, and the model's range of validity.

5.2 A time domain, computer simulation program was developed for the turning circle, zigzag, and spiral manoeuvres. The model was based primarily upon research work reported in reference 7 (Annex A). In addition, empirical formulae were incorporated into the program. These formulae provided estimates of turning circle and crash stop performance, and were obtained from references 8 and 9 (Annex A).

6.0 FULL-SCALE TRIALS

6.1 Full-scale trials were conducted during the project on a laker and a ferry. These vessels were chosen because they represented a majority of the ships which comprise the Canadian merchant fleet. Conducting the trials served three (3) purposes.

.1 Firstly, accurate full-scale data was gathered which was then compared to the estimated results obtained from the mathematical model.

.2 Secondly, the practicality of using the standard data recording sheets, contained in the "Sea Trials Program" was assessed.

.3 Thirdly, it was reported in an earlier study (ref. 10, Annex A) and in a submission to the Sub-Committee (DE 31/3), that data contained in a manoeuvring database showed a high degree of scatter for lakers and ferries. Data from the full scale trials was compared directly to the data contained in the manoeuvring database.

6.2 The trials which were conducted on the laker and ferry were the following:

o 35^0 turning circle to port and starboard;

- $10^0/10^0$ zigzag manoeuvre;
- $20_0/20^0$ zigzag manoeuvre;
- spiral manoeuvre, and
- crash stop manoeuvre.

Environmental conditions were very favorable for all of the trials.

7.0 COMPARISON OF RESULTS

7.1 The results for the laker turning circle manoeuvre are summarized in Tables C-1 to C-4 of Annex C, and are presented in Figures C-1 and C-2. In general, the basic parameters of the turning circle manoeuvre, (ie., advance, transfer, tactical diameter and steady turning diameter), obtained from the computer simulation and empirical formulae were within 10% of the full-scale trial results.

7.2 Results are presented in Tables C-5, C-6 and C-7 for the laker simulated and full-scale zigzag manoeuvres. The simulated results, in comparison to the full-scale data, are not as consistent as those of the turning circle manoeuvre.

7.3 The simulated spiral manoeuvre did not accurately estimate the magnitudes of steady turning rates for the laker or ferry. However, the correct trends were predicted. For example, from the full-scale results, the laker was dynamically stable in the ballast condition and unstable in the loaded condition. Both of these characteristics were predicted by the computer model.

7.4 The results for the ferry turning circle manoeuvre were underestimated by the computer simulation (see Tables C-8, C-9 and Figure C-3, Annex C). It should be noted that the basis for the computer model (ref. 7, Annex A) was developed for single screw vessels. The ferry which was tested had a twin screw/twin rudder arrangement. The algorithm was modified in an effort to accommodate ships such as the ferry, however, it would appear from the results of the turning circle manoeuvre that further work is required.

7.5 Tables C-10 and C-11 summarize the ferry zigzag manoeuvres. As was the case for the laker, there were only a few parameters which were predicted with a reasonable level of accuracy.

7.6 Crash stop results for both vessels are summarized in Table C-12. The empirical estimates of head reach for the two vessels were generally within 10% of the actual full-scale results.

8.0 SENSITIVITY ANALYSIS

8.1 During the preliminary design phase of a project, the naval architect works with a range of values for many of the design parameters. The method selected for the manoeuvring model (ref. 7, Annex A) was developed for use during the design process, primarily because it only relied on information available during the early stages of a design.

8.2 A limited sensitivity analysis was conducted as a part of this research project. Using the laker turning circle as a basis for the analysis, four (4) parameters were varied within a reasonable range of values that would be known to a navel architect. The parameters were the propeller blade area ratio (BAR), pitch to diameter ratio (P/D), rudder wake fraction (WR), and propeller wake fraction (WP).

8.3 It was discovered that the model was highly sensitive to all four of the parameters. For example, the steady turning diameter of the ship changed by 10% within the range of BAR; by 31% when P/D was varied, by 10% for the WR, and by 14% when WP was changed.

9.0 FUTURE WORK

9.1 The results of this study will be brough to the attention of the marine industry in Canada. In particular, the proposed "Sea Trials Program" will be distributed for discussion and feedback prior to formal implementation of the program.

9.2 The manoeuvring model will be tested, on a continuing basis, to further validate the program. Available full-scale and model test data will be used to conduct an extensive sensitivity analysis. In addition, further development will take place with respect to the modelling of twin screw ships.

10.0 DISCUSSION

10.1 This program has highlighted a number of issues central to the regulation of manoeuvring performance. Certain conclusions can be drawn from the results outlined above.

10.2 No satisfactory general method currently exists to preduct the full range of manoeuvring characteristics of ships using information available to the naval architect in the preliminary stages of design, or typically made available to national regulatory bodies by designer and owner. For most vessels, accuracy of prediction of performance must continue to rely on model tests. If standards of performance are to be enforced, prudent naval architects will therefore be obliged to include such tests in the design process.

10.3 If any national regulatory authority wishes to validate the information provided in a vessel's pilot card, bridge poster, or manoeuvring booklet, it must be present or represented at the sea trials. For the results of any trials to be accepted internationally, standards for the content and conduct of these trials will have to be agreed.

10.4 It appears from the results of work conducted in Canada that not all manoeuvring data contained in existing pilot cards, etc., accurately represents the actual performance of the ships. A concern therefore exists that the provision of inaccurate information to pilots or inexperienced ships officers may increase the risk of their attempting inappropriate manoeuvres in hazardous situations.

10.5 A more general concern is that even high quality deep water performance predictions and measurements provide little insight into performance in shallow and/or restricted waters. It is under these conditions that good manoeuvrability is most often needed. Until better methods for linking measured performance to other conditions are developed, the benefits or regulating deep water characteristics will remain limited.

ANNEX A

REFERENCES

1) "Recommendation on Information to be Included in the Manoeuvring Booklets", Revised Resolution A209 (VII), International Maritime Organization, May, 1986.

2) Panel M-19 (Ship Trials) of the SNAME Ship's Machinery Committee, "Code of Sea Trials - 1973", SNAME Technical and Research Code C-2, 1974.

3) "Code of Procedure for Steering and Manoeuvring Trials", British Ship Research Association, Report NS. 353, 1972.

4) Landsberg, A.C., et. al.; "Proposed Shipboard Manoeuvring Data", proceedings of the Fifth Ship Technology and Research (STAR) Symposium, San Diego, 1980.

5) "Report of the Manoeuvrability Committee", proceeding of the 14th International Towing Tank Conference, 1975.

6) "Rules for Nautical Safety" from DnV Rules for Construction of Steel Ships, 1987.

7) Inoue, S.; et al; "A Practical Calculation Method of Ship Manoeuvring Motion", International Shipbuilding Progress, Vol. 28, No. 325, May 1981.

8) "Ship Manoeuvring and Control", Principles of Naval Architecture, Chapter VIII, published by the Society of Naval Architects and Marine Engineers, 1977.

9) Lyster, C.A. and Knights, H.L.; "Prediction Equations for Ships' Turning circles", Trans of the North East Coast Institution of Engineers and Shipbuilders, Vol. 95, No. 4, July 1979.

10) Kendrick, A. and Lantos, S.; "Study for the Development of Canadian and International Ship Navigation Standards", prepared for Canadian Coast Guard, German & Milne Report No. 7235 - R.05, March, 1987.

11) "Technical Basis for Manoeuvring Performance Standards", prepared by Hydronautics Inc., for U.S. Coast Guard, December, 1981.

ANNEX B

Sea Trials Program

TRIAL CATEGORY: OPEN WATER PERFORMANCE

TRIAL NAME: TURNING CIRCLE MANOEUVRE

TRIAL OBJECTIVE:

To determine the effectiveness of the rudder to produce steady-state turning characteristics.

EQUIPMENT REQUIRED/PREPARATIONS FOR RECORDING DATA:

Microwave positioning system.
Yaw Gyro.

Three remote stations, consisting of microwave transponders shall be installed ashore and the distances between them measured. The master station shall be installed on the highest possible spot of the ship.

The ship's doppler speed log may be used to determine the ship's track providing sea conditions are good, a "bottom lock" is achieved and the accuracy requirements of ≤ 10m or one ship breadth are met. However, the ship's doppler speed log should only be used to support the microwave position system readings.

ENVIRONMENTAL CONDITIONS REQUIRED:

SEA: ≤ Sea State 3

CURRENT: Constant, < 1 m/s

WIND SPEED: ≤ Beaufort 4

VESSEL APPROACH SPEED: See note 1 of procedure

WATER DEPTH REQ'D >:

WATER DEPTH REQ'D, $D = \frac{5.522HV}{\sqrt{L_{pp}}}$

WHERE D=Minimum depth (m)
H=Trial draft (m)
V=Approach speed (knots)
Lpp=Length between perpendiculars (m)

TRIAL CATEGORY : OPEN WATER PERFORMANCE

TRIAL NAME : TURNING CIRCLE MANOEUVRE

PROCEDURE :

To be performed for both the loaded and ballast operating conditions, as well as to both port and starboard.

1. Hold ship steady on a constant heading at a specified approach speed (1) for approximately one (1) minute. Once approach speed is "steadied", propulsion controls are not to be manipulated for duration of manoeuvre.
2. Record relevant data in section A of datasheet. Commencing one (1) minute before "Rudder Hardover" command, record ship's heading and position at 10 second intervals throughout the manoeuvre in the respective datasheets.
3. Move rudder hardover to starboard (2) and hold until the ship's heading has changed by 540°.
4. Resume a straight course and restore speed.
5. Repeat step 3, moving rudder hardover to port.

NOTES :

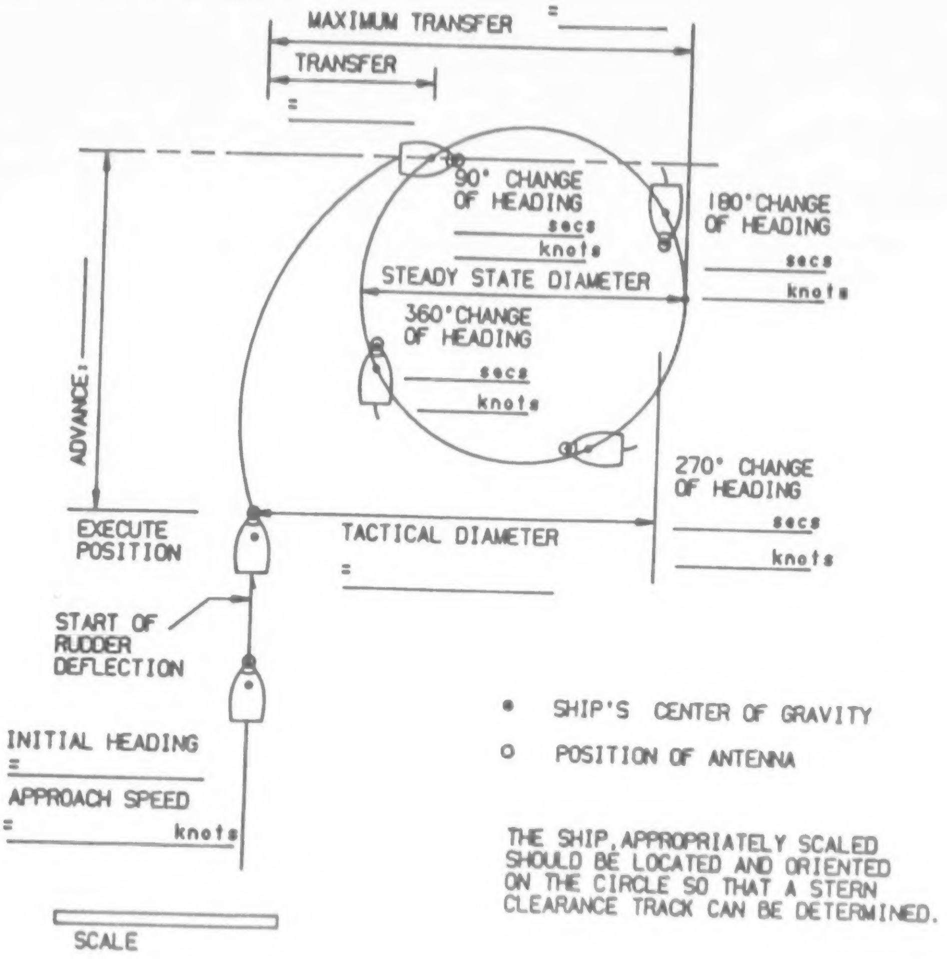
1. The throttle setting for a single screw vessel should not be changed during the manoeuvre, however, for multi-screw ships, the throttle may be adjusted as necessary to correct unacceptable overspeed or overtorque. If a throttle adjustment is required during the turn, the manoeuvre should be repeated at a reduced approach speed at which a hard turn can be made without throttle adjustment.
2. Maximum rudder angle is to be applied.

TRIAL CATEGORY:	OPEN WATER PERFORMANCE
TRIAL NAME:	TURNING CIRCLE MANOEUVRE

RESULTS:

The ship's heading versus time is to be plotted for all engine settings listed on the datasheets. If a land-based recording system is used, the plot must be corrected for drift (Ref. App. A). The plot should be for starboard turns only, unless there is significant difference for port turns.

PRESENTATION OF RESULTS:



THE SHIP, APPROPRIATELY SCALED SHOULD BE LOCATED AND ORIENTED ON THE CIRCLE SO THAT A STERN CLEARANCE TRACK CAN BE DETERMINED.

THE TURNING CIRCLE MANOEUVRE

SHIP OPERATING CONDITION: ______________

DRAFT AFT: ________ DRAFT FWD: ______________

TRIAL CATEGORY: OPEN WATER PERFORMANCE

TRIAL NAME : TURNING CIRCLE MANOEUVRE

RESULTS:

SHIP'S NAME : ______________________

TRIAL LOCATION: ______________________

ITEM		ENGINE SETTING: Full Speed Ahead, Constant Engine Setting											
		LOADED						BALLAST					
		PORT			STARBOARD			PORT			STARBOARD		
INITIAL SHAFT RPM													
INITIAL SPEED, KNOTS													
INITIAL HEADING													
RUDDER ANGLE													
WIND DIRECTION													
WIND FORCE													
SEA STATE													
ELAPSED TIME AND SHIP SPEED FOR THE VESSEL TO TURN, deg.		min	sec	kts	min	sec	kts	min	sec	kts	min	sec	kts
	10												
	20												
	90												
	180												
	270												
	360												
	450												
	540												
ADVANCE													
MAX'M. ADVANCE													
TRANSFER													
MAX'M. TRANSFER													
TACTICAL DIAMETER													
STEADY-STATE DIAMETER													
FINAL SPEED													
FINAL RPM													
DRIFT CORRECTION DIRECTION													

MANOEUVRE : ______________________________

SHIP'S OPERATING CONDITION : ________________

ENGINE SETTING: ____________________________

IT SHOULD BE NOTED THAT THE RESPONSE OF THE VESSEL MAY BE DIFFRENT FROM THAT SHOWN IF ANY OF THE FOLLOWING CONDITIONS UPON WHICH THE MANOEUVRING DATA IS BASED, ARE ALTERED:

1. CALM WEATHER ≤ SEA STATE 3
2. WIND ≤ BEAUFORT 4
3. DRAFTS AS SHOWN
4. DEEP WATER CONDITION
5. CONSTANT CURRENT <1 M/S
6. CLEAN HULL

TRIAL CATEGORY: OPEN WATER PERFORMANCE

TRIAL NAME: TURNING CIRCLE MANOEUVRE

CONDUCTING AUTHORITY:

OWNER'S REPRESENTATIVE:

PERFORMED BY:

AUTHORIZED BY:

SHIP MASTER:

A DATA:

SHIP NAME:
TEST DATE:
SHIP'S OPERATING CONDITION:
DEPTH OF WATER:
SEA CONDITION:
WIND VELOCITY:
WIND DIRECTION:
DRAFT AFT.:
DRAFT FWD.:
TRIM :
TRIAL LOCATION :

ITEM	PORT	STARBOARD
TIME TEST BEGAN		
TIME TEST ENDED		
SHIP'S HEADING		
INITIAL RUDDER ANGLE		
INITIAL SHAFT RPM.		
APPROACH SPEED		
CONTROLLABLE PITCH SETTING (IF APPL.)		

EQUIPMENT USED: (Ie. Manufacturer, Model no., Serial no.)

TRIAL CATEGORY : OPEN WATER PERFORMANCE

TRIAL NAME : TURNING CIRCLE MANOEUVRE

CONDUCTING AUTHORITY :

OWNER'S REPRESENTATIVE :

PERFORMED BY :

AUTHORIZED BY :

SHIP MASTER :

B DATA:

SHIP'S OPERATING CONDITION : ______________________________

ENGINE SETTING: ______________________________

PORT			STARBOARD		
TIME (sec.)	HEADING (deg.)	RATE OF TURN (deg./sec.)	TIME (sec.)	HEADING (deg.)	RATE OF TURN (deg./sec.)
FINAL SPEED			FINAL SPEED		
FINAL RPM			FINAL RPM		

TRIAL CATEGORY: OPEN WATER PERFORMANCE

TRIAL NAME: TURNING CIRCLE MANOEUVRE

CONDUCTING AUTHORITY:

OWNER'S REPRESENTATIVE:

PERFORMED BY:

AUTHORIZED BY :

SHIP MASTER :

C DATA:

SHIP'S OPERATING CONDITION: ____________________

PORT				STARBOARD			
TIME (sec.)	POSITION (deg.)	TIME (sec.)	POSITION (deg.)	TIME (sec.)	POSITION (deg.)	TIME (sec.)	POSITION (deg.)

TRIAL CATEGORY:	OPEN WATER PERFORMANCE
TRIAL NAME :	TURNING CIRCLE MANOEUVRE

DRIFT CORRECTION:

ENGINE SETTING: ____________________

SHIP'S OPERATING CONDITION:____________________

PORT OR STARBOARD :____________________

INITIAL HEADING :____________________

TIME (sec.)	HEADING FROM BASE COURSE (deg.)	CHANGE IN HEADING (deg.)	POSITION (deg.)

ANNEX C

Comparison of Results

WORK ORDER NO.: 7320 - R.01 JANUARY 30, 1989

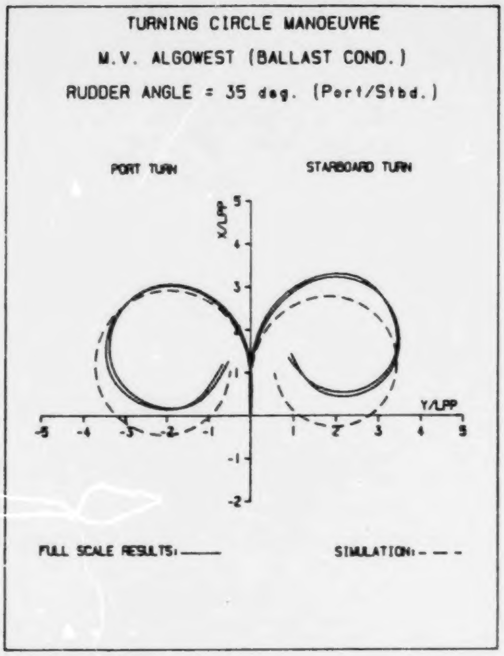


FIGURE C-1: Laker Turning Circle Manoeuvre - Ballast Condition

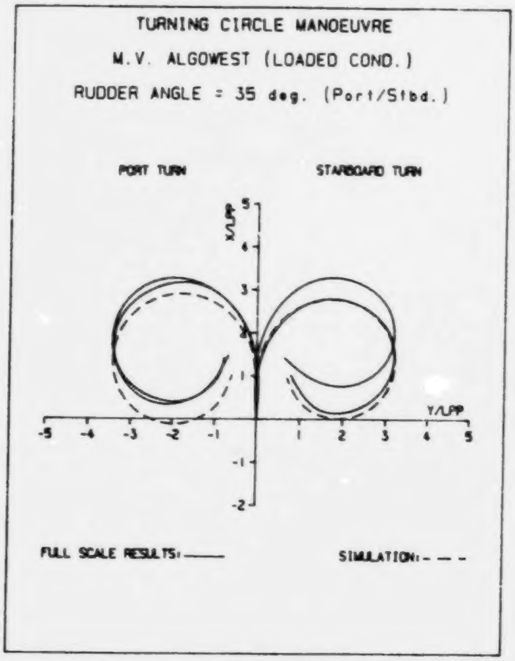


FIGURE C-2: Laker Turning Circle Manoeuvre - Loaded Condition

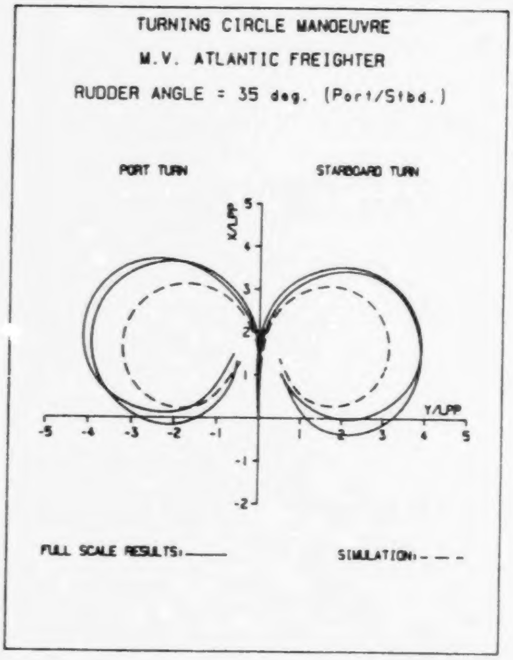


FIGURE C-3: Ferry Turning Circle Manoeuvre

35° STBD. CIRCLE

PARAMETER	TRIAL #1	TRIAL #2	EMPIRICAL	SIMULATION
Non-dimensional* Advance	3.19	3.21	3.22	2.72
Non-dimensional* Transfer	1.63	1.46	1.74	1.38
Non-dimensional* Tactical Diameter	3.59	3.31	3.64	3.37
Non-dimensional* Steady Turning Diameter	2.73	2.64	3.04	2.75
Final Speed (knots)	6.4	7.4	5.23	8.5

*Non-dimensionalized by length between perpendiculars

TABLE C-1: Laker Turning Circle Results - Ballast Condition

35° PORT CIRCLE

PARAMETER	TRIAL #1	TRIAL #2	EMPIRICAL	SIMULATION
Non-dimensional* Advance	2.98	3.00	3.63	2.86
Non-dimensional* Transfer	1.53	1.49	2.14	1.49
Non-dimensional* Tactical Diameter	3.32	3.29	4.44	3.66
Non-dimensional* Steady Turning Diameter	2.79	2.90	3.92	3.13
Final Speed (knots)	5.8	6.3	5.97	9.3

*Non-dimensionalized by length between perpendiculars

TABLE C-2: Laker Turning Circle Results - Ballast Condition

35° STBD. CIRCLE

PARAMETER	TRIAL #1	TRIAL #2	EMPIRICAL	SIMULATION
Non-dimensional* Advance	3.27	2.78	2.87	2.71
Non-dimensional* Transfer	1.50	1.5	1.41	1.26
Non-dimensional* Tactical Diameter	3.09	3.13	2.97	3.13
Non-dimensional* Steady Turning Diameter	2.4	2.43	2.34	2.38
Final Speed (knots)	5.1	4.7	3.87	6.06

*Non-dimensionalized by length between perpendiculars

TABLE C-3: Laker Turning Circle Results - Loaded Condition

35° PORT CIRCLE

PARAMETER	TRIAL #1	TRIAL #2	EMPIRICAL	SIMULATION
Non-dimensional* Advance	3.16	3.23	3.28	2.84
Non-dimensional* Transfer	1.57	1.63	1.81	1.36
Non-dimensional* Tactical Diameter	3.31	3.35	3.77	3.34
Non-dimensional* Steady Turning Diameter	2.61	2.76	3.21	2.70
Final Speed (knots)	4.9	5.4	4.49	6.91

*Non-dimensionalized by length between perpendiculars

TABLE C-4: Laker Turning Circle Results - Loaded Condition

PARAMETER	TRIAL	SIMULATION
Overshoot Angle (degrees)	8.0	12.0
Non-dimensional * Overshoot Width of Path	1.13	1.3
Period (secs.)	374	270
Non-dimensional* Reach	5.16	4.3

* Non-dimensionalized by length between perpendiculars

TABLE C-5: Laker 20°/20° Zigzag Results - Loaded Condition

PARAMETER	TRIAL	SIMULATION
Overshoot Angle (degrees)	7.0	6.9
Non-dimensional * Overshoot Width of Path	Not Available	0.73
Period (secs.)	371	257
Non-dimensional* Reach	6.17	4.44

* Non-dimensionalized by length between perpendiculars

TABLE C-6: Laker 10°/10° Zigzag Results - Loaded Condition

PARAMETER	TRIAL	SIMULATION
Overshoot Angle (degrees)	5.0	6.7
Non-dimensional * Overshoot Width of Path	0.68	0.74
Period (secs.)	269	190
Non-dimensional* Reach	4.24	3.44

* Non-dimensionalized by length between perpendiculars

TABLE C-7: Laker 20°/20° Zigzag Results - Ballast Condition

35° STBD. CIRCLE

PARAMETER	TRIAL #1	TRIAL #2	EMPIRICAL	SIMULATION
Non-dimensional* Advance	3.5	3.39	2.91	3.02
Non-dimensional* Transfer	1.75	1.72	1.51	1.30
Non-dimensional* Tactical Diameter	3.82	3.77	3.52	3.10
Non-dimensional* Steady Turning Diameter	3.58	3.39	3.38	2.59
Final Speed (knots)	10.8	9.6	12.2	8.05

*Non-dimensionalized by length between perpendiculars

TABLE C-8: Ferry Turning Circle Results

35° PORT CIRCLE

PARAMETER	TRIAL #1	TRIAL #2	EMPIRICAL	SIMULATION
Non-dimensional* Advance	3.64	3.61	2.91	3.07
Non-dimensional* Transfer	1.80	1.74	1.51	1.33
Non-dimensional* Tactical Diameter	3.86	4.02	3.52	3.17
Non-dimensional* Steady Turning Diameter	3.41	3.51	3.38	2.70
Final Speed (knots)	9.5	9.8	12.19	8.34

*Non-dimensionalized by length between perpendiculars

TABLE C-9: Ferry Turning Circle Results

PARAMETER	TRIAL	SIMULATION
Overshoot Angle (degrees)	12.0	19.7
Non-dimensional * Overshoot Width of Path	1.75	1.74
Period (secs.)	130	147
Non-dimensional* Reach	4.25	4.91

* Non-dimensionalized by length between perpendiculars

TABLE C-10: Ferry 20°/20° Zigzag Results

PARAMETER	TRIAL	SIMULATION
Overshoot Angle (degrees)	8.0	8.81
Non-dimensional * Overshoot Width of Path	1.18	0.8
Period (secs.)	108	121
Non-dimensional* Reach	5.12	4.67

* Non-dimensionalized by length between perpendiculars

TABLE C-11: Ferry 10°/10° Zigzag Results

PARAMETER	LAKER LOADED CONDITION	LAKER BALLAST CONDITION	FERRY
Non-dimensional* Head Reach	4.52 6.31	4.92 5.21	4.74 4.63
Non-dimensional* Track Length	5.09 6.84	6.35 5.26	4.83 4.72
Time to Stop (secs.)	304 342	277 278	145 115
Empirical** Head Reach	6.79	4.36	4.48

* Non-dimensionalized by length between perpendiculars.
** Non-dimensional head reach estimated using empirical formula.

Note: Values from two (2) trials are quoted in the table.

TABLE C-12: Crash Stop Results